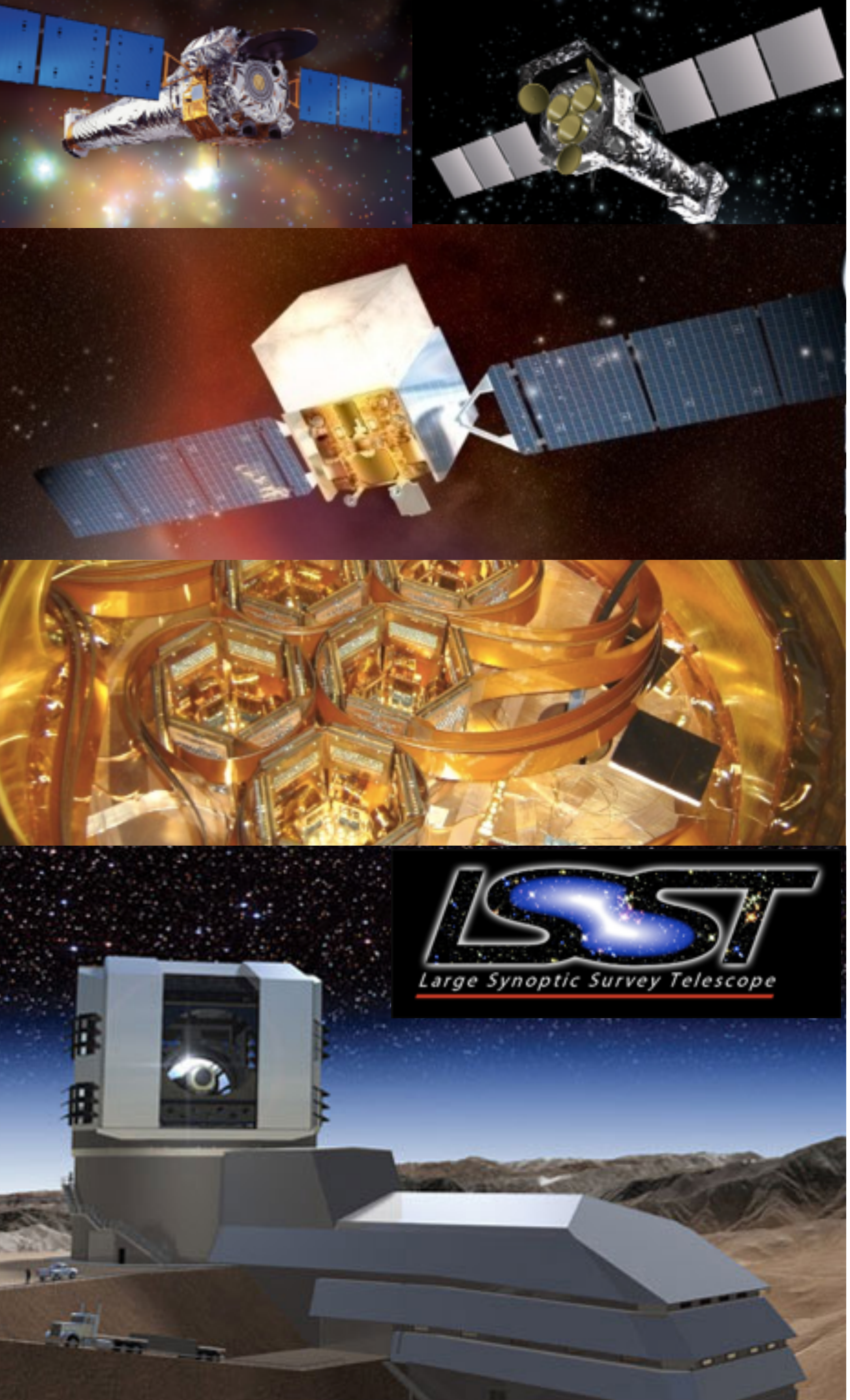


Fermilab

Using LSST to Probe the Fundamental Nature of Dark Matter

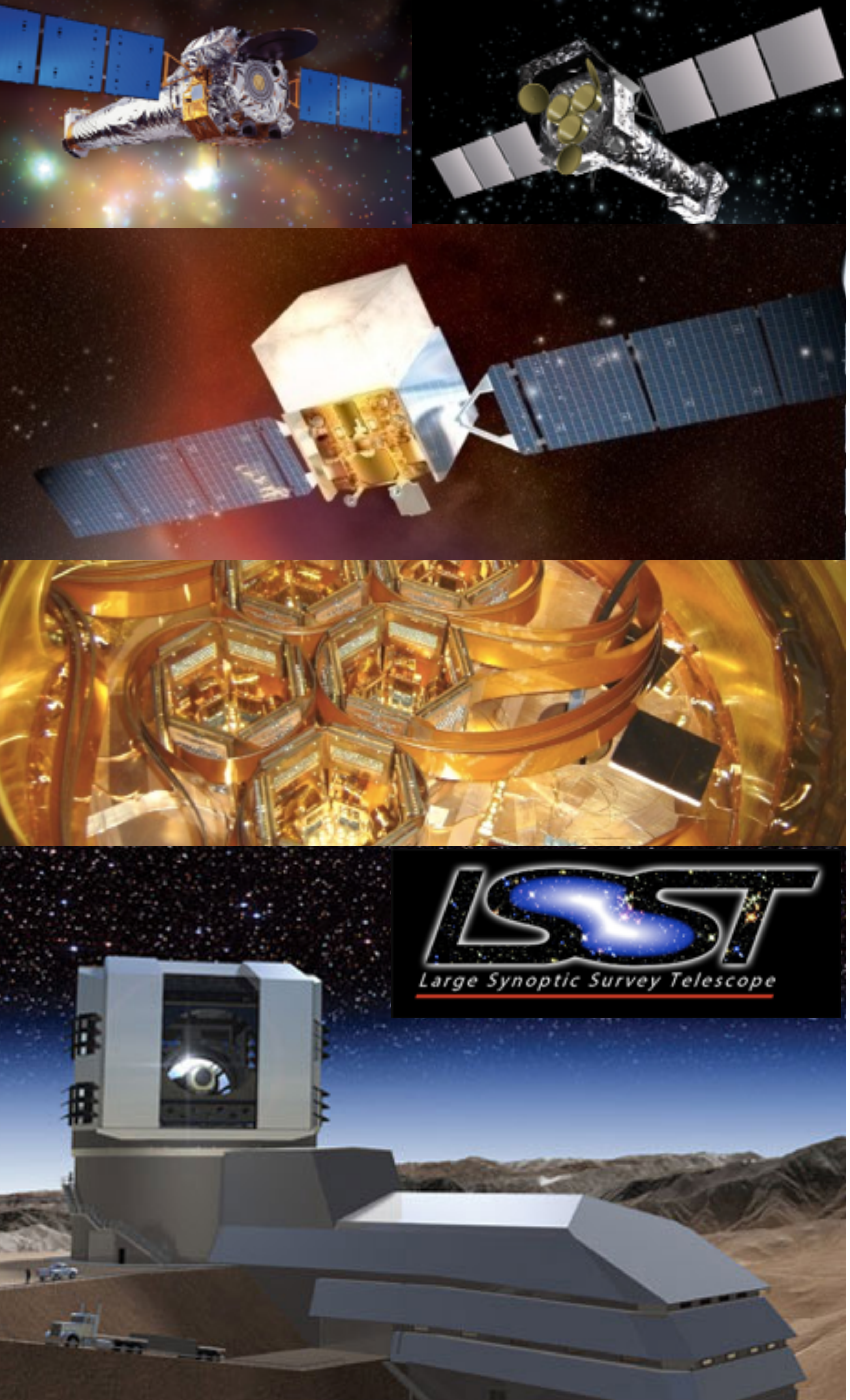
...OR...

Alex Drlica-Wagner

LSST Cross-Correlation Workshop

May 25, 2016

Fermilab | Center for Particle Astrophysics



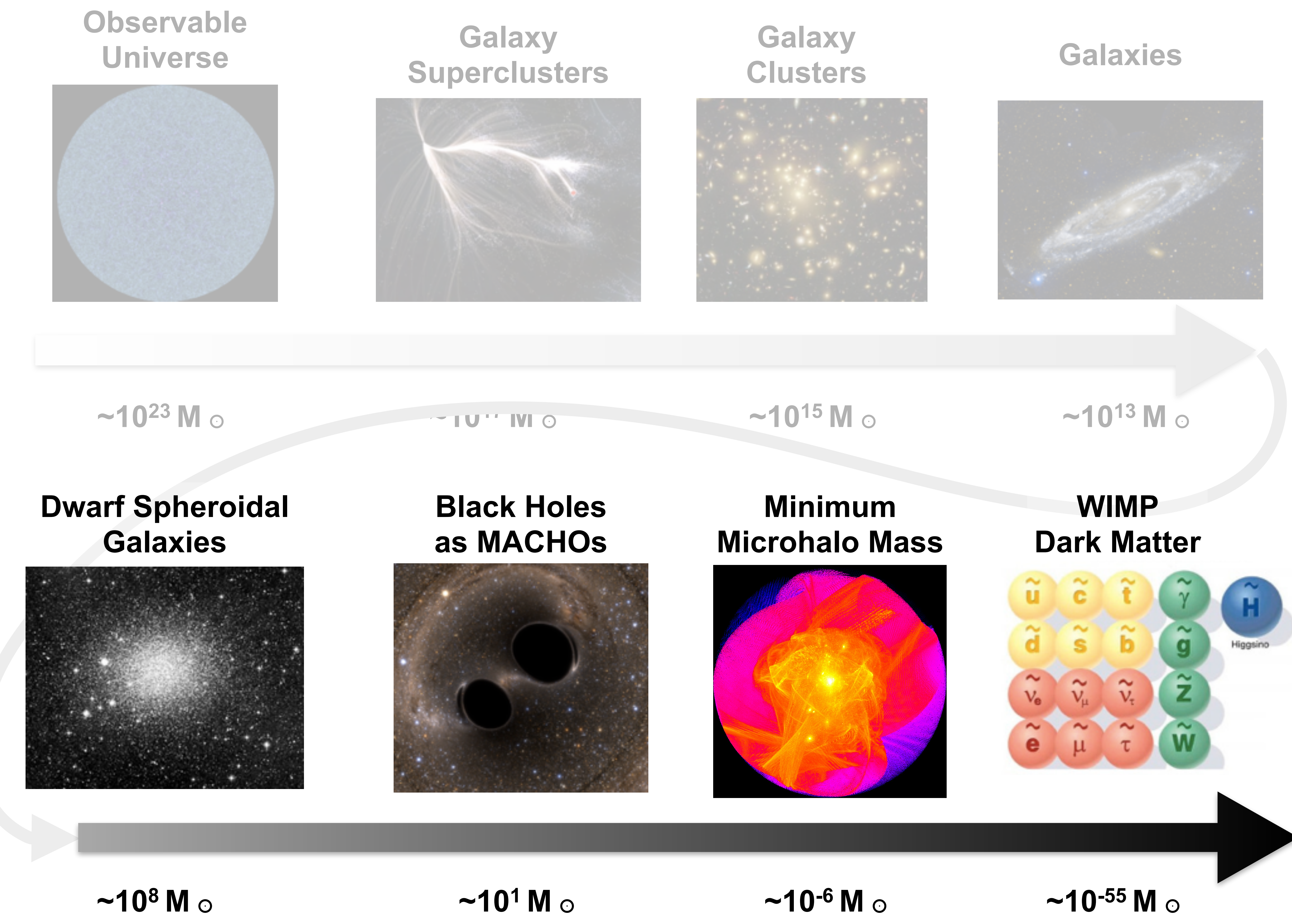
Fermilab

A Jam Session about Multi-Wavelength Multi-Messenger Synergistic Cross-Correlations for Probing the Nature of Dark Matter

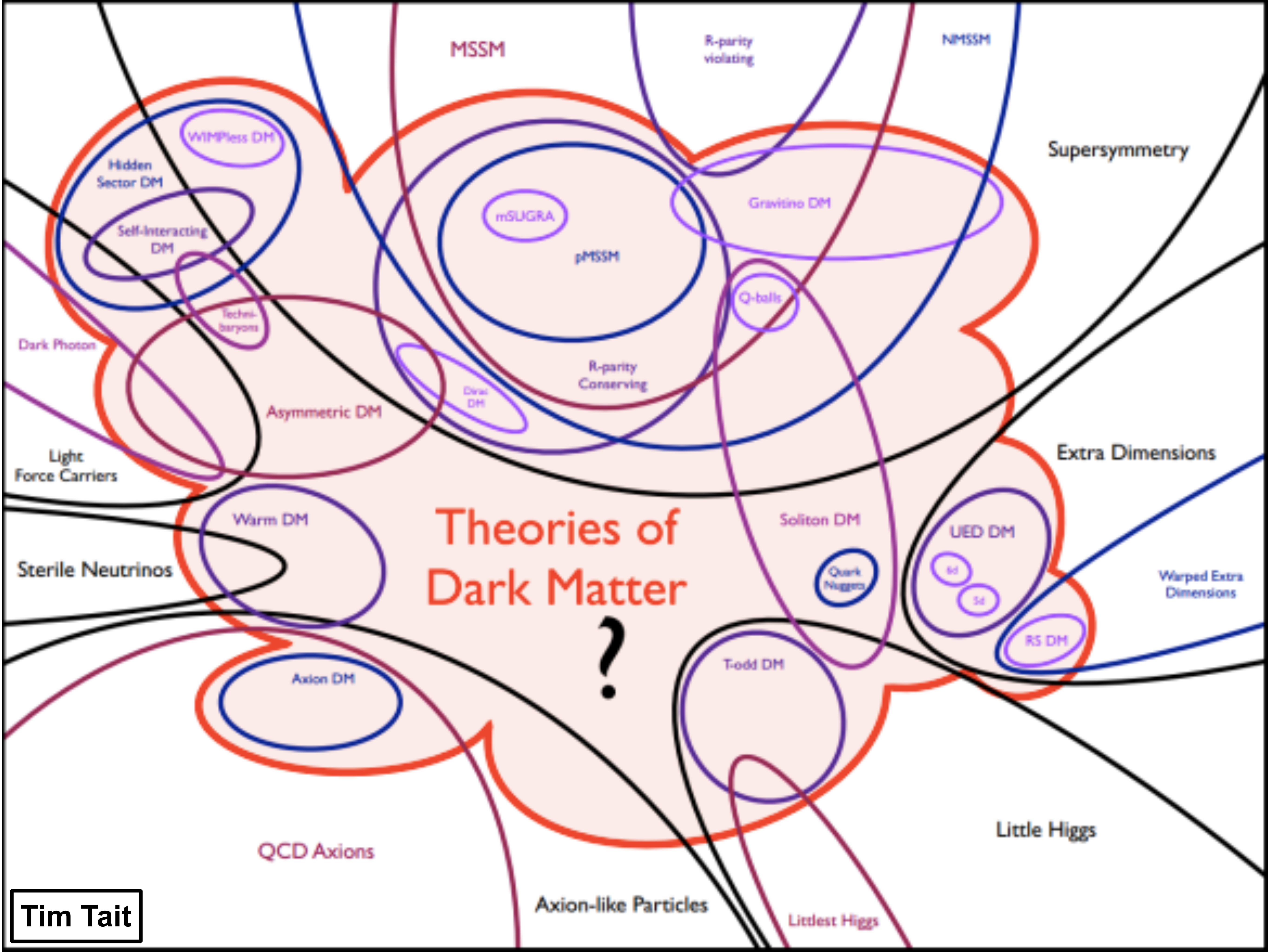
Alex Drlica-Wagner

LSST Cross-Correlation Workshop
May 25, 2016

Fermilab | Center for Particle Astrophysics

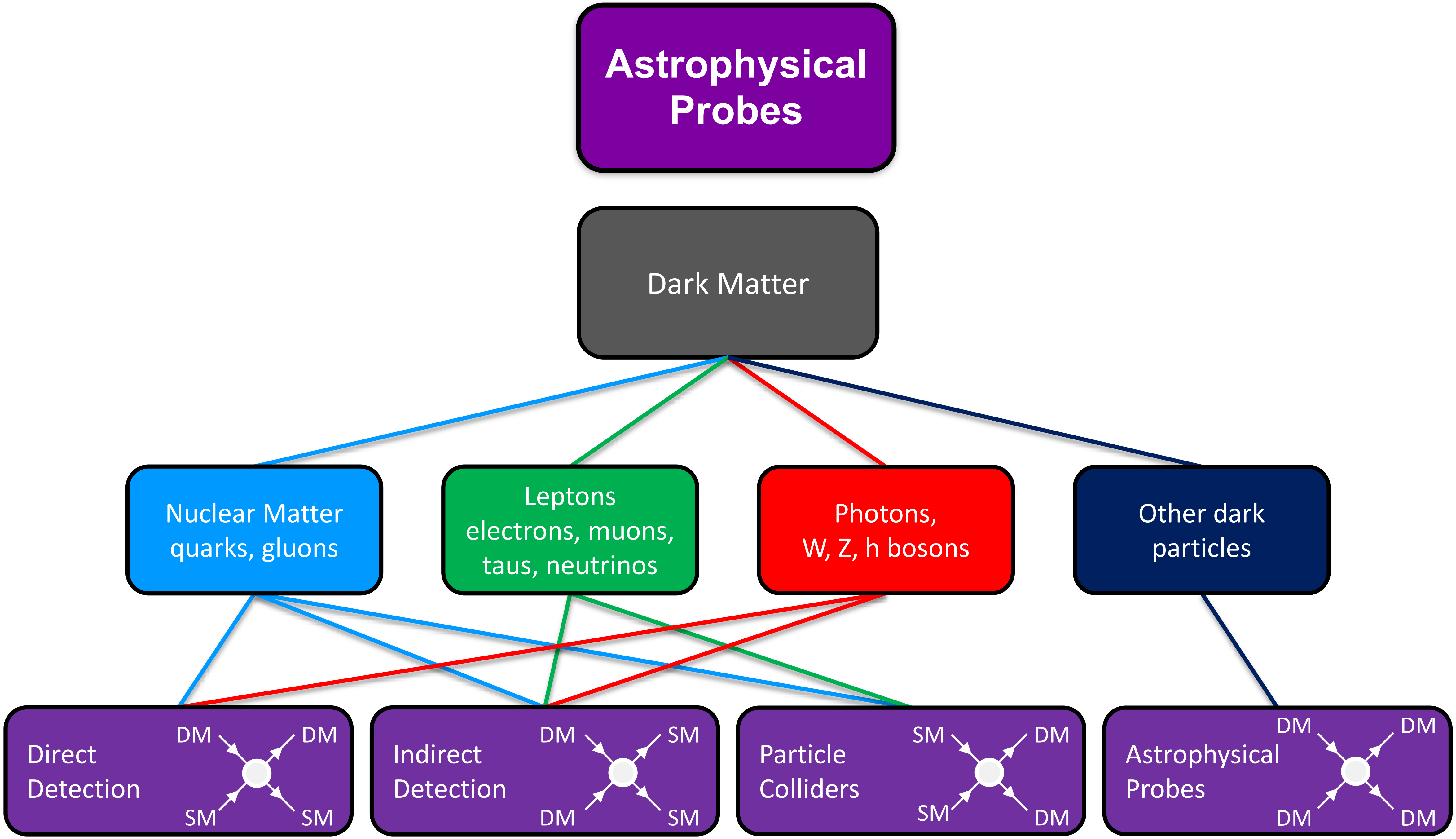


Observable Universe
Galaxy Superclusters
Galaxy Clusters
Galaxies
~10^{23} M$_\odot$
~10^{15} M$_\odot$
~10^{13} M$_\odot$
Dwarf Spheroidal Galaxies
Black Holes as MACHOs
Minimum Microhalo Mass
WIMP Dark Matter
Higgsino
~10^{8} M$_\odot$
~10^{1} M$_\odot$
~10^{-6} M$_\odot$
~10^{-55} M$_\odot$



Theories of Dark Matter
?
MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
Dark Photon
mSUGRA
pMSSM
Gravitino DM
Q-balls
R-parity Conserving
Dirac DM
Asymmetric DM
Light Force Carriers
Extra Dimensions
Warm DM
Soliton DM
UED DM
Sterile Neutrinos
Quark Nuggets
Warped Extra Dimensions
RS DM
Axion DM
T-odd DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
Tim Tait

"Pillars" of Dark Matter

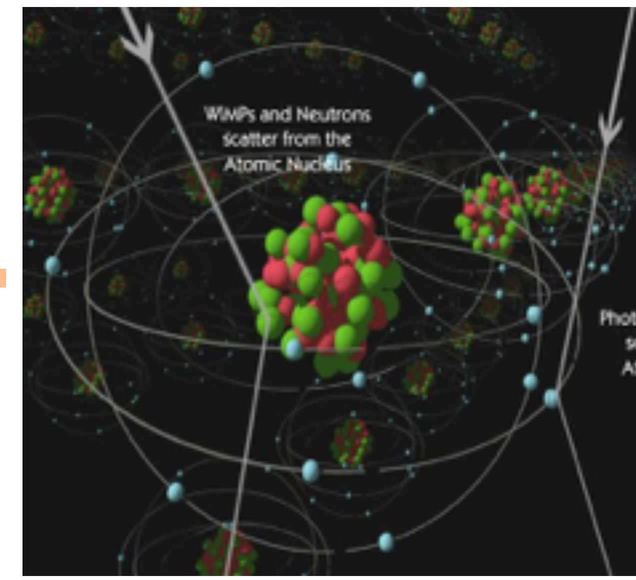


Snowmass CF4 (1305.1605)

Direct Detection

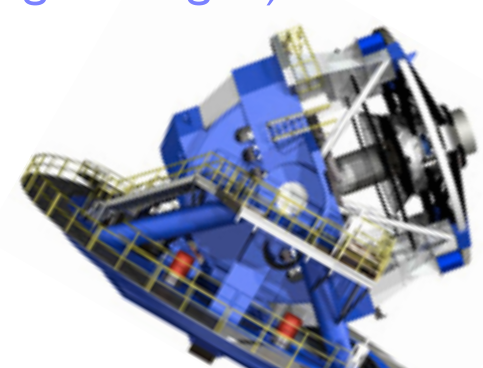
Differential Event Rate
(signal in data)

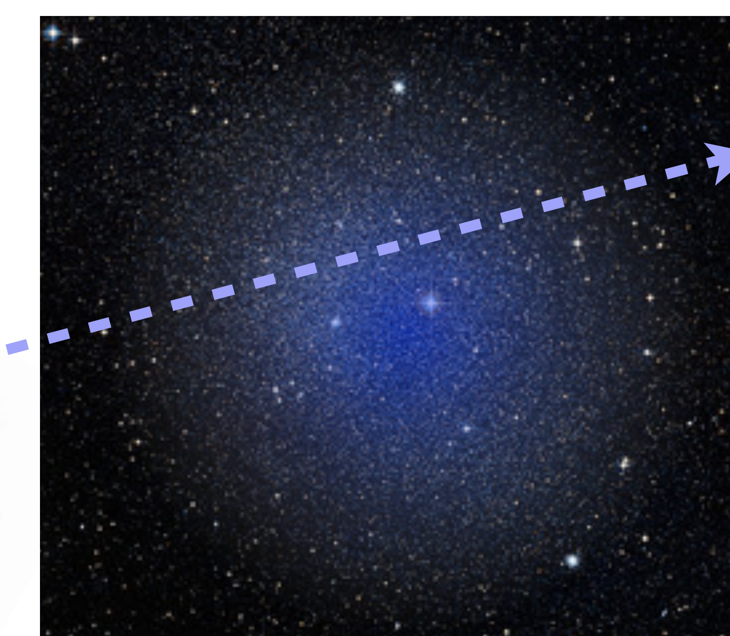
Particle & Nuclear Physics
(cross section & form factor)



$$\frac{dN}{dE_r} = \frac{\sigma_0}{2\mu^2 m_{\rm DM}} F(q)^2 \times \rho_{\rm DM} \int_{v_{\rm min}}^{v_{\rm esc}} \frac{f(v)}{v} dv$$

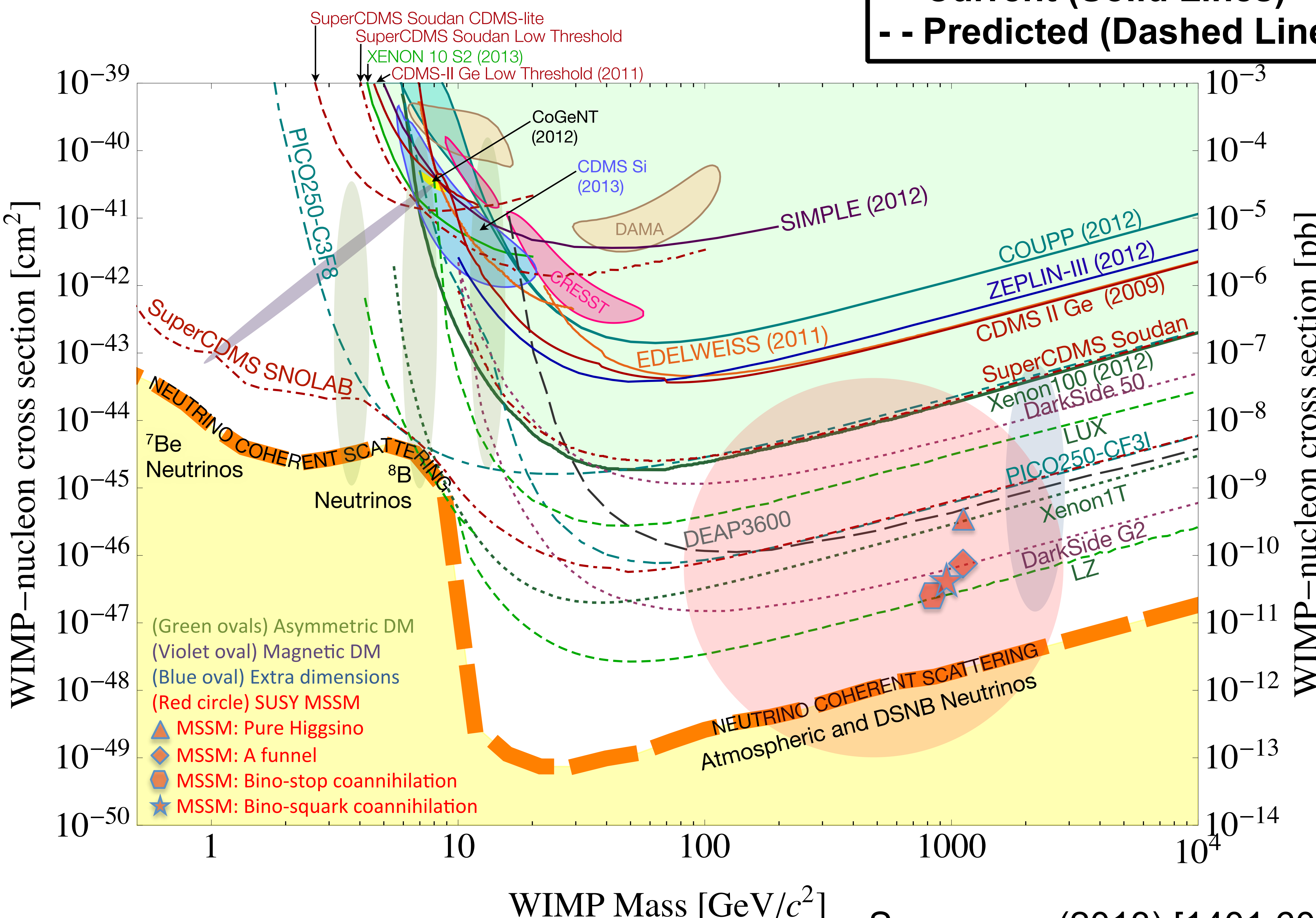
Local Dark Matter Distribution
(line-of-sight integral)





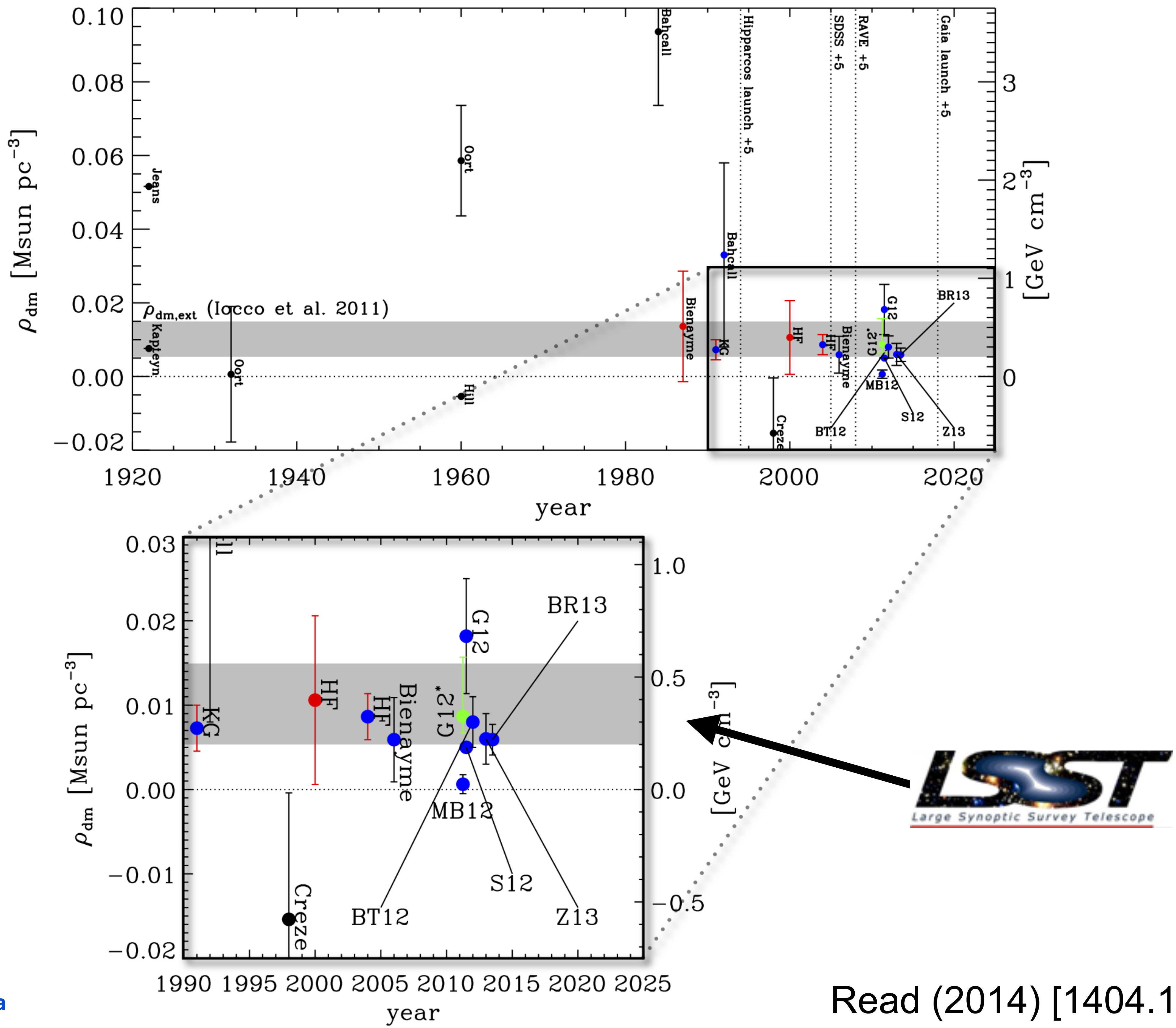
Direct Detection

— Current (Solid Lines)
- - Predicted (Dashed Lines)



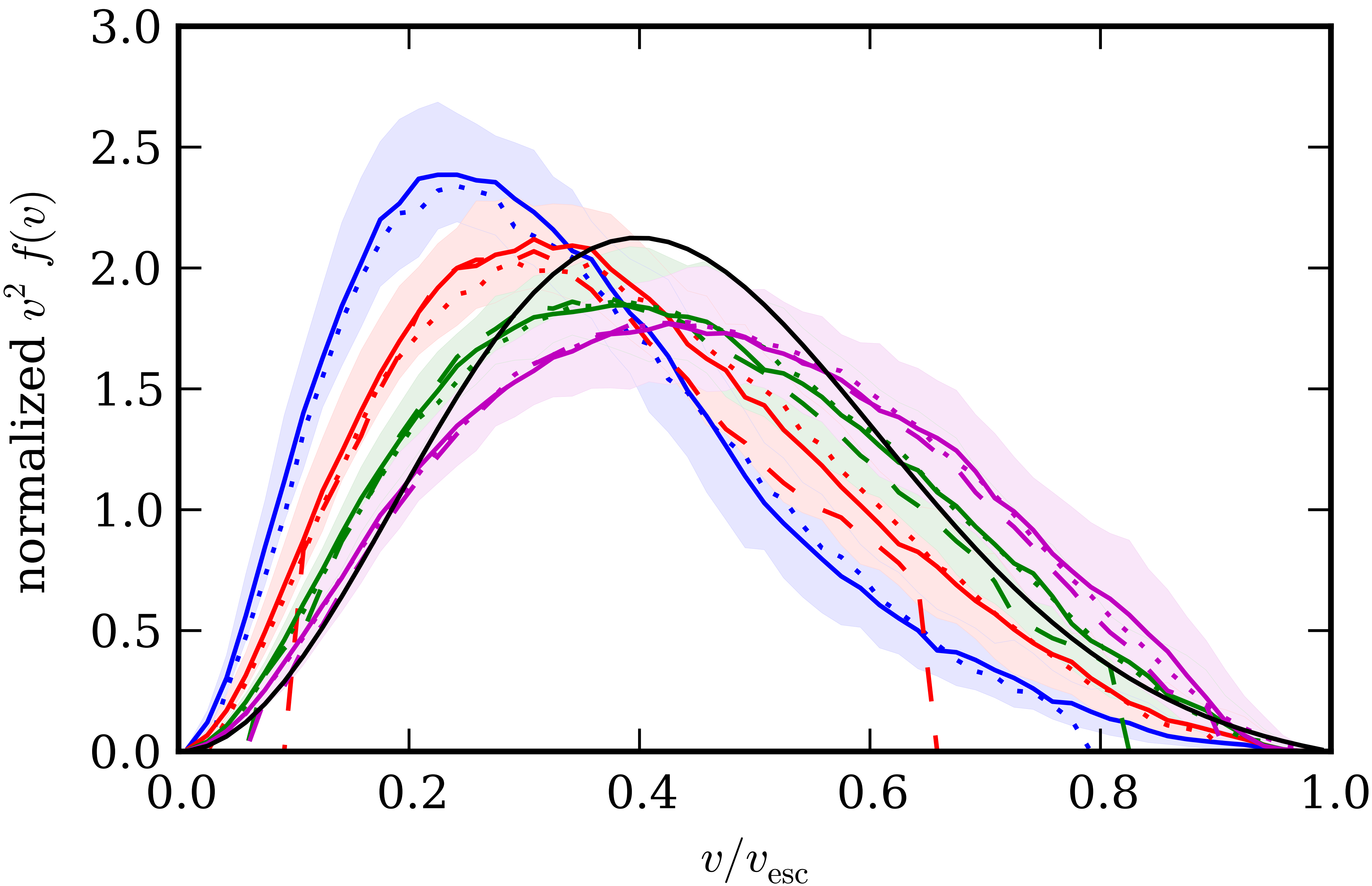
Snowmass (2013) [1401.6085]

Local Dark Matter Density



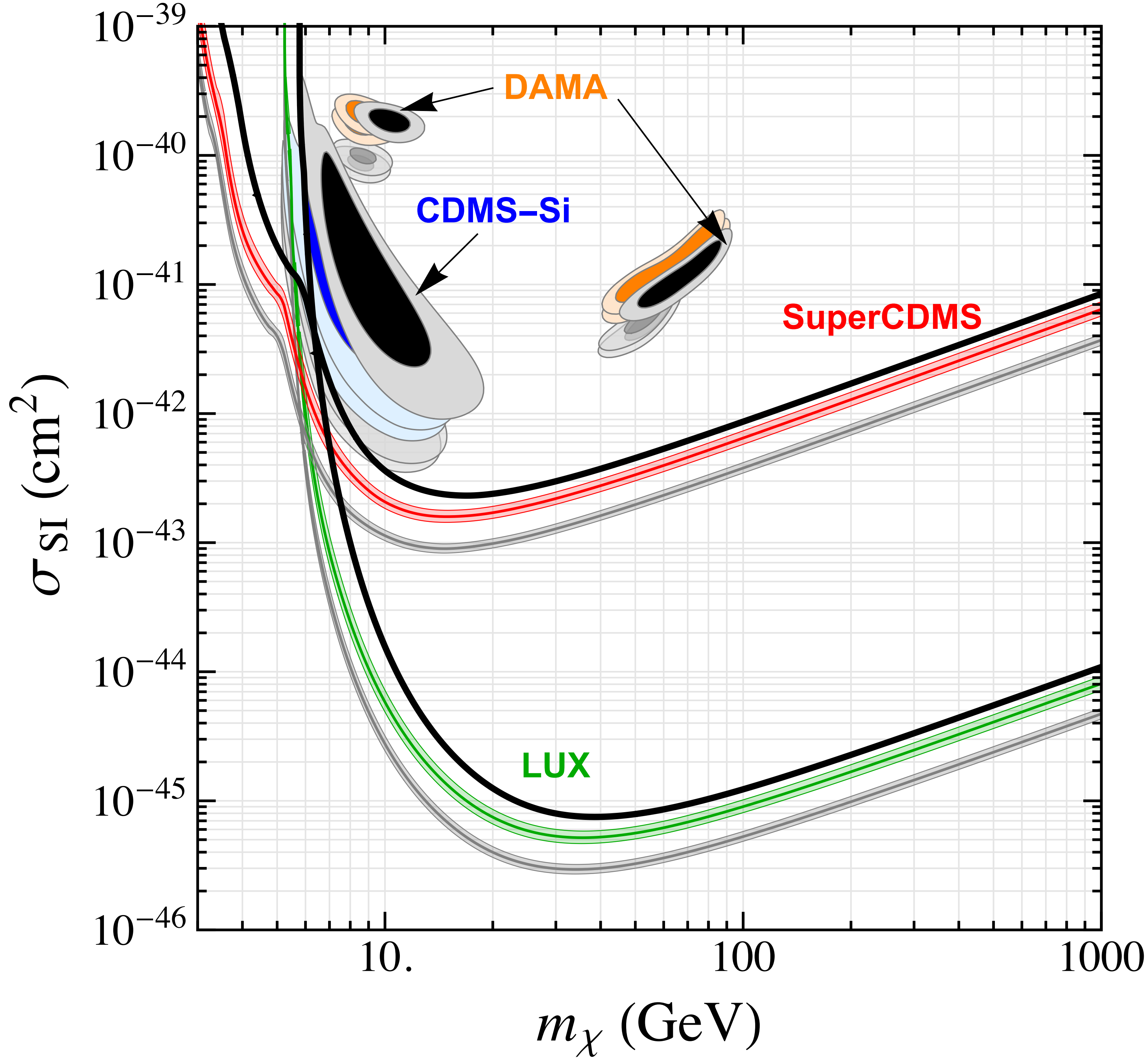
Read (2014) [1404.1938]

Local Dark Matter Velocity



Mao et al. (2012) [1210.2721]

Direct Detection



Bozorgnia et al. 2016 [1601.04707]

Indirect Detection

Particle Flux

(signal in data)

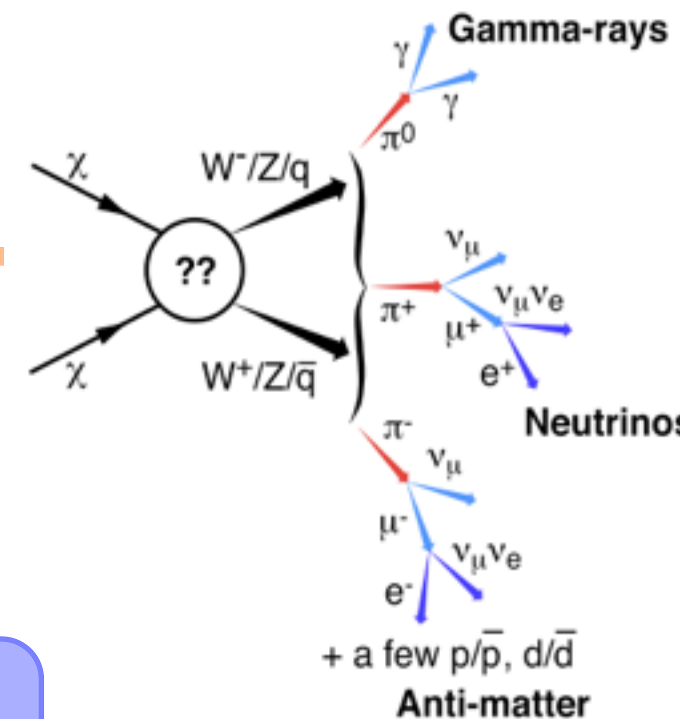
Particle Physics

(photons per annihilation)

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f$$

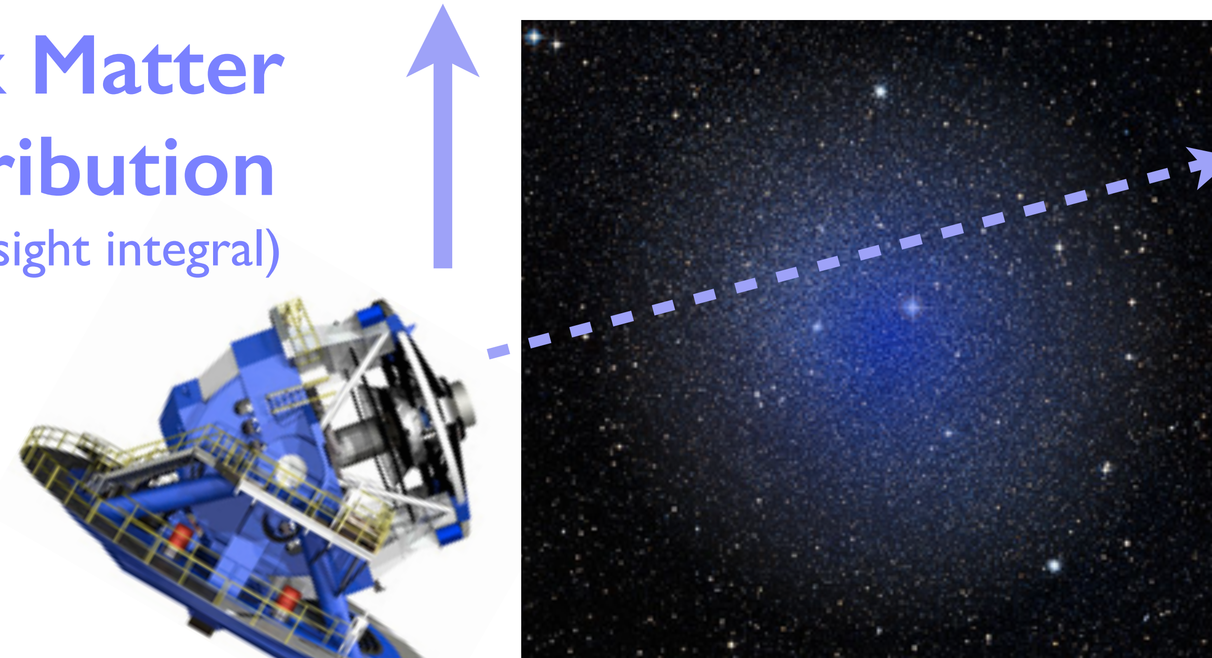
$$\times$$

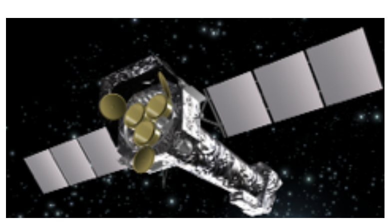
$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los}\rho^2(r(l,\phi'))dl(r,\phi')$$



Dark Matter Distribution

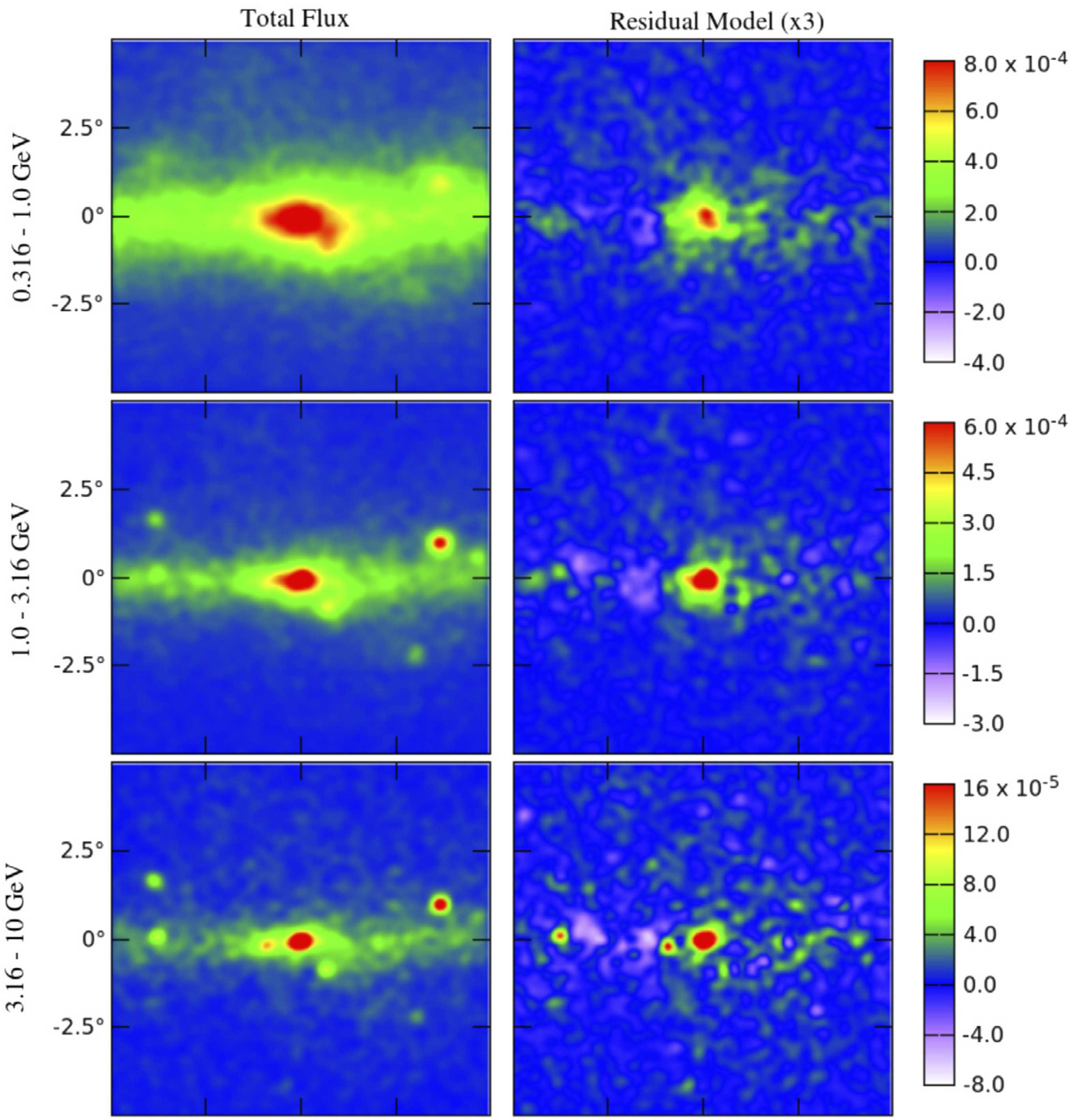
(line-of-sight integral)





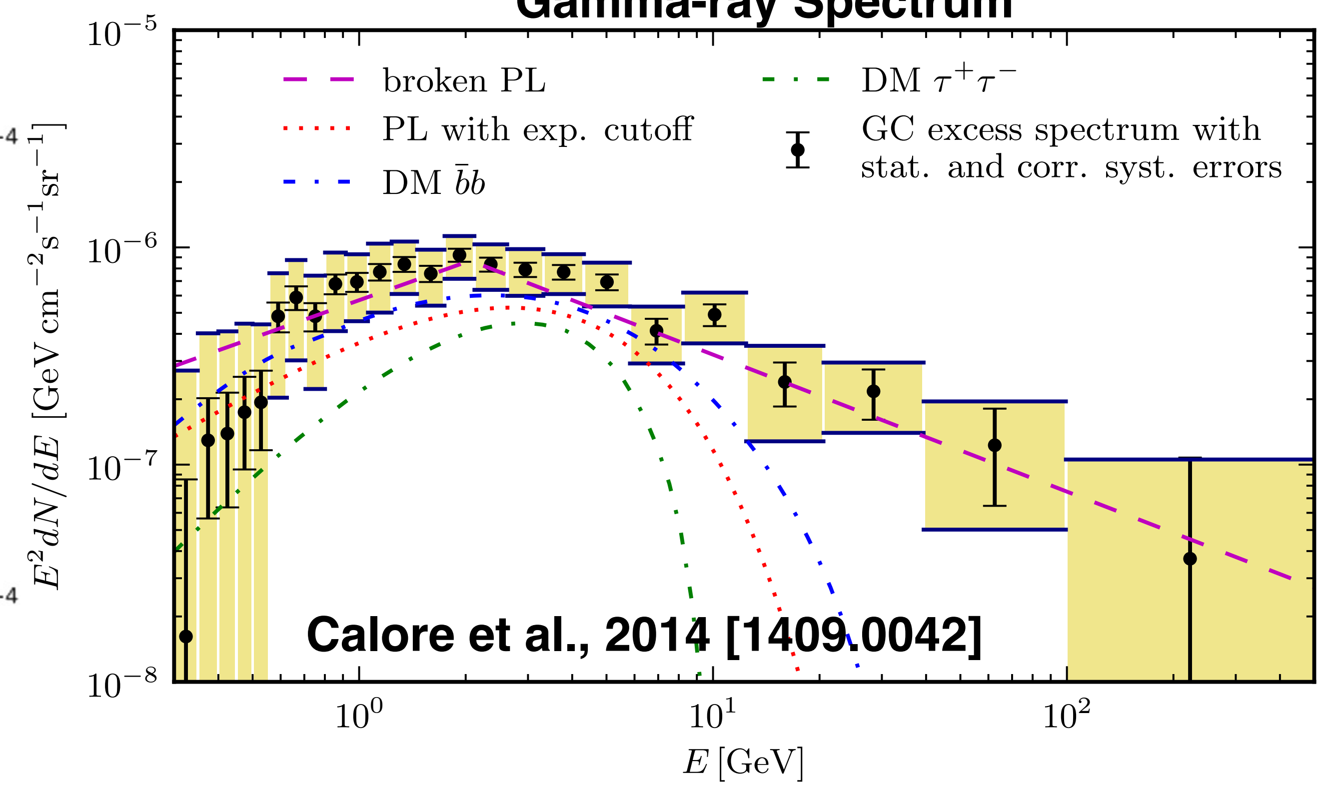
Galactic Center

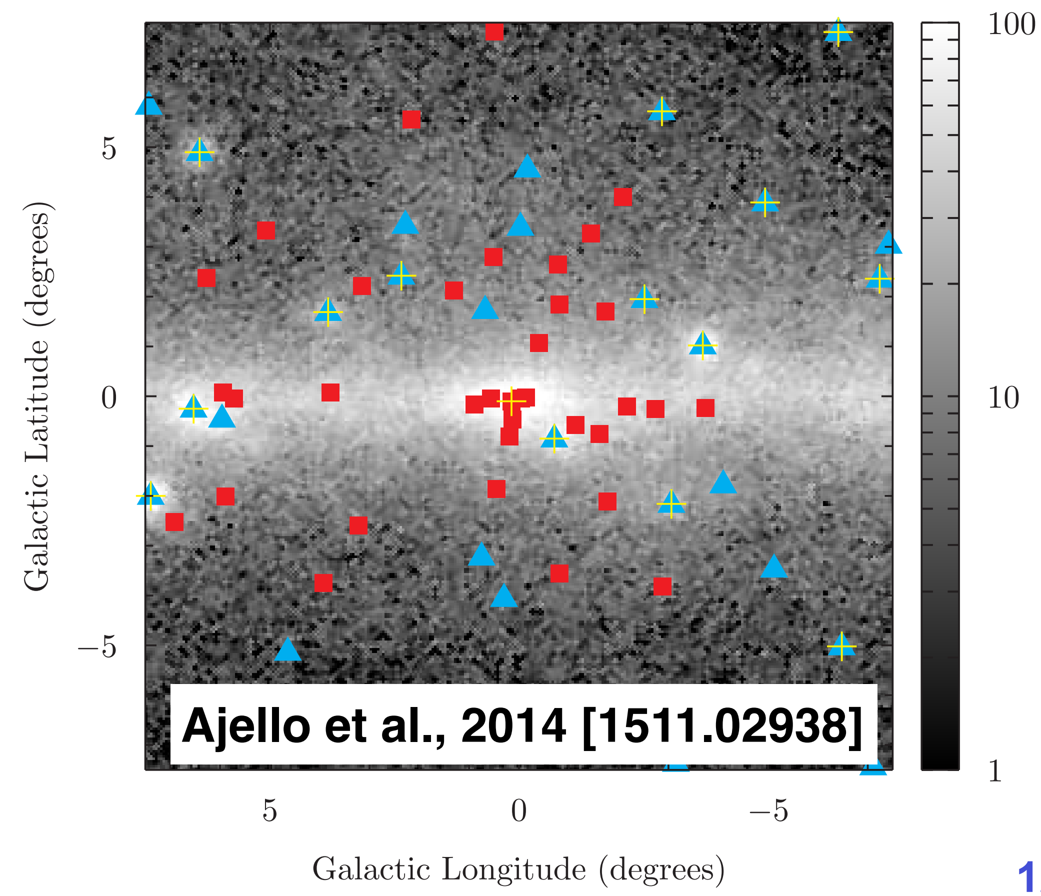
Spatial Map



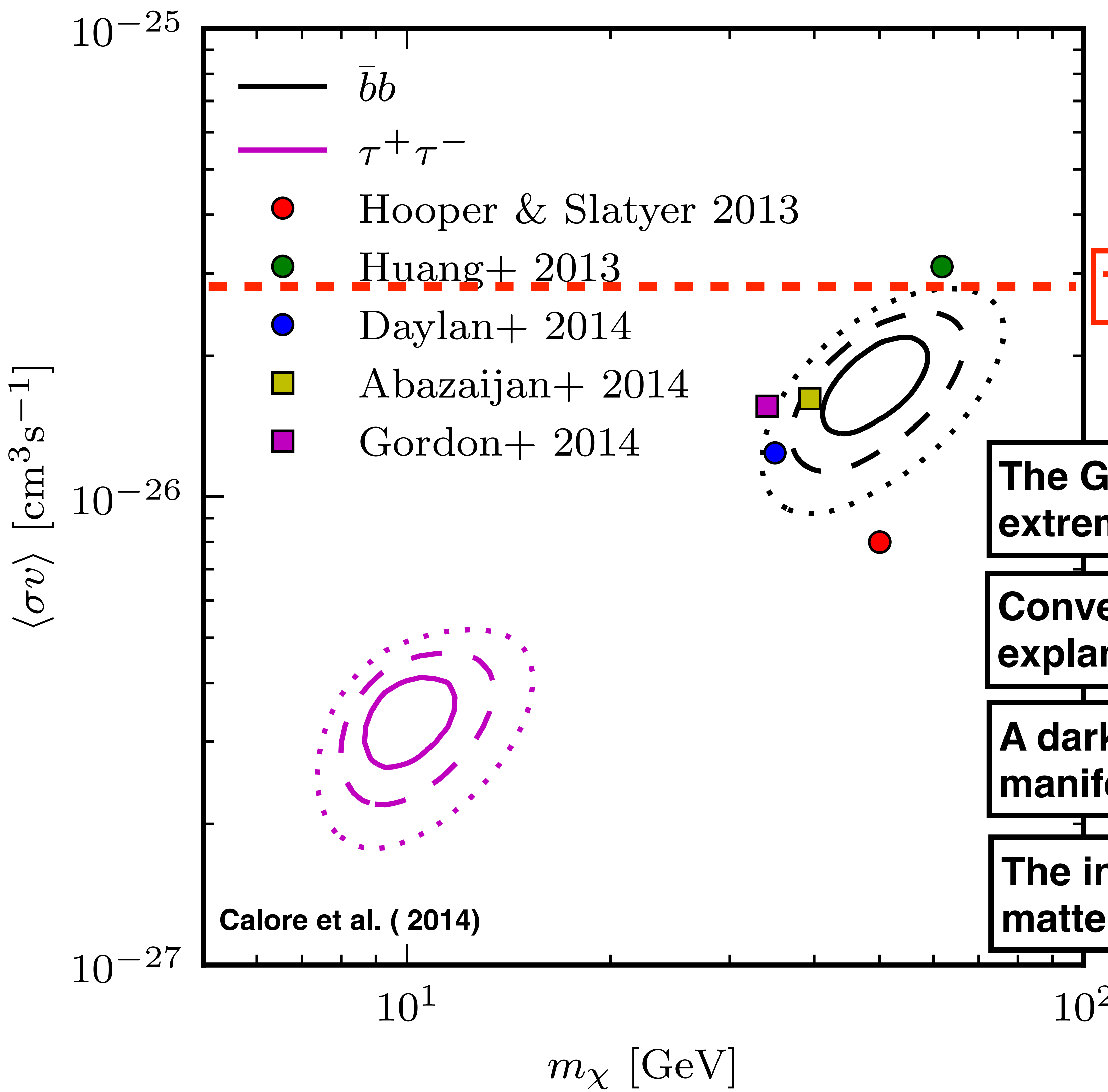
Daylan et al., 2014 [1402.6703]

Gamma-ray Spectrum





Galactic Center



The Galactic Center is an extremely complicated region

Conventional astrophysical explanations exist (e.g. pulsars)

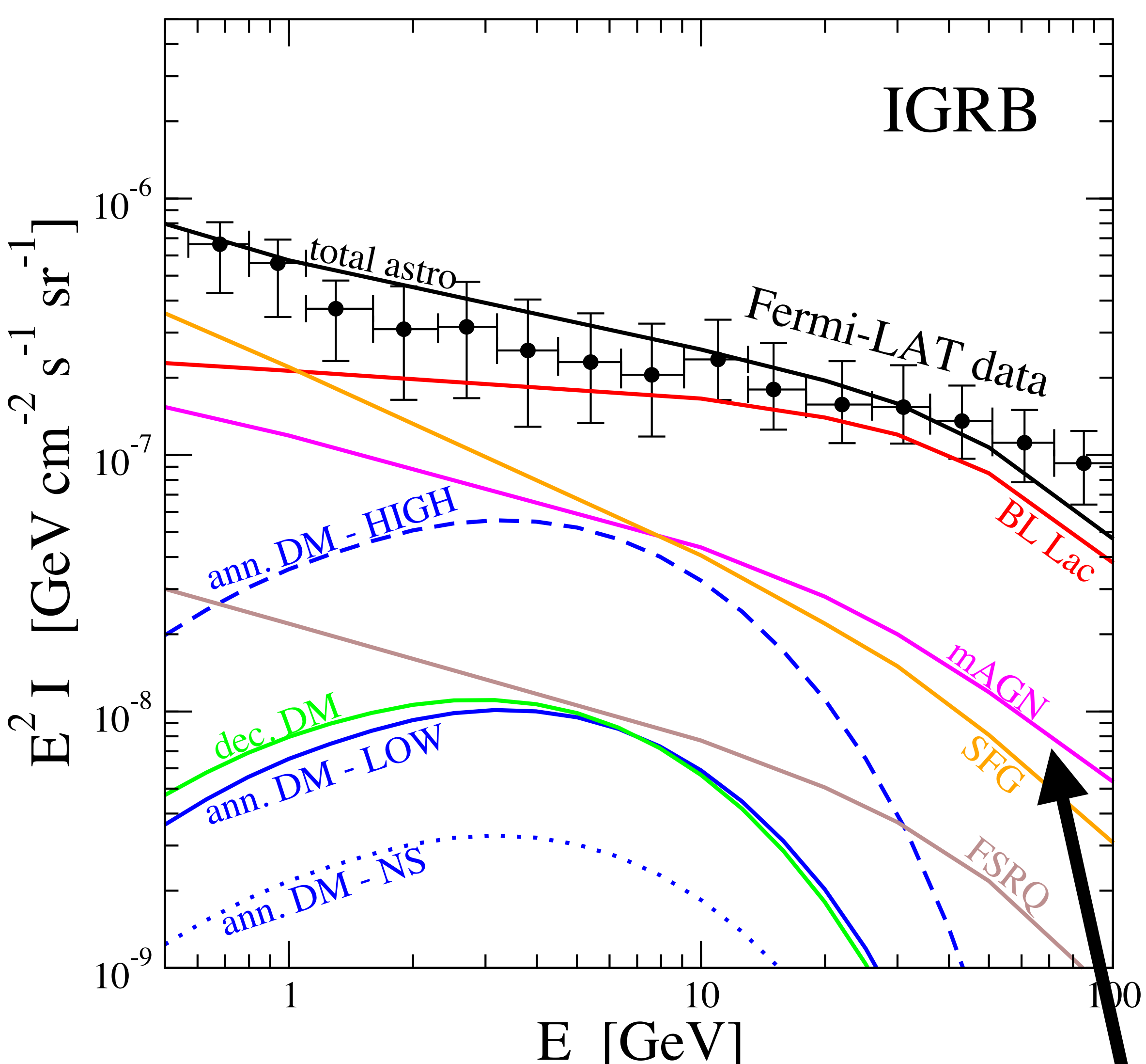
A dark matter signal should manifest itself in other regions

The investigation of other dark matter targets is essential

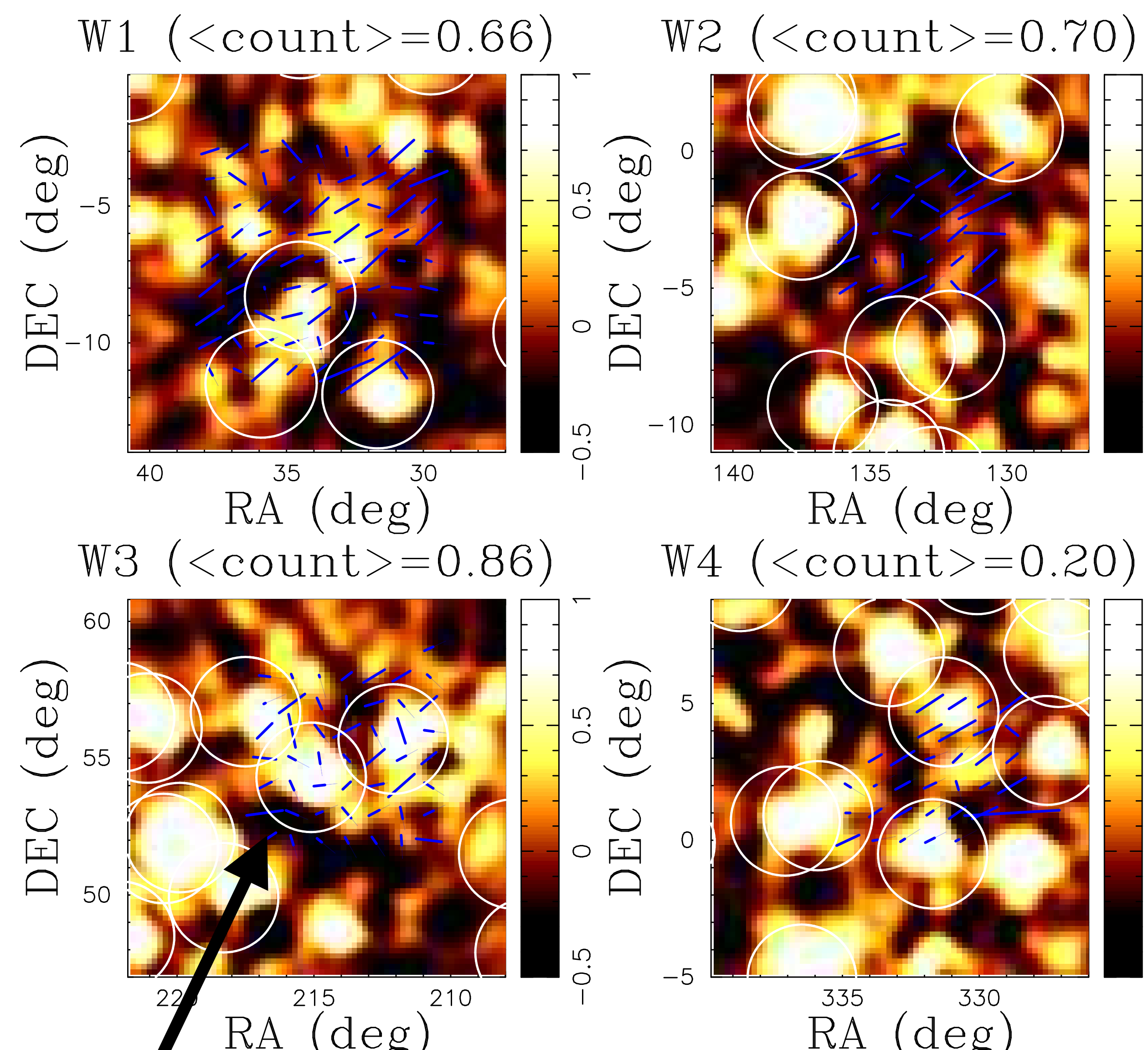
Extragalactic Background

Actual Cross-Correlation!

Fermi-LAT & Galaxy Catalogs



Fermi-LAT x CFHTLenS

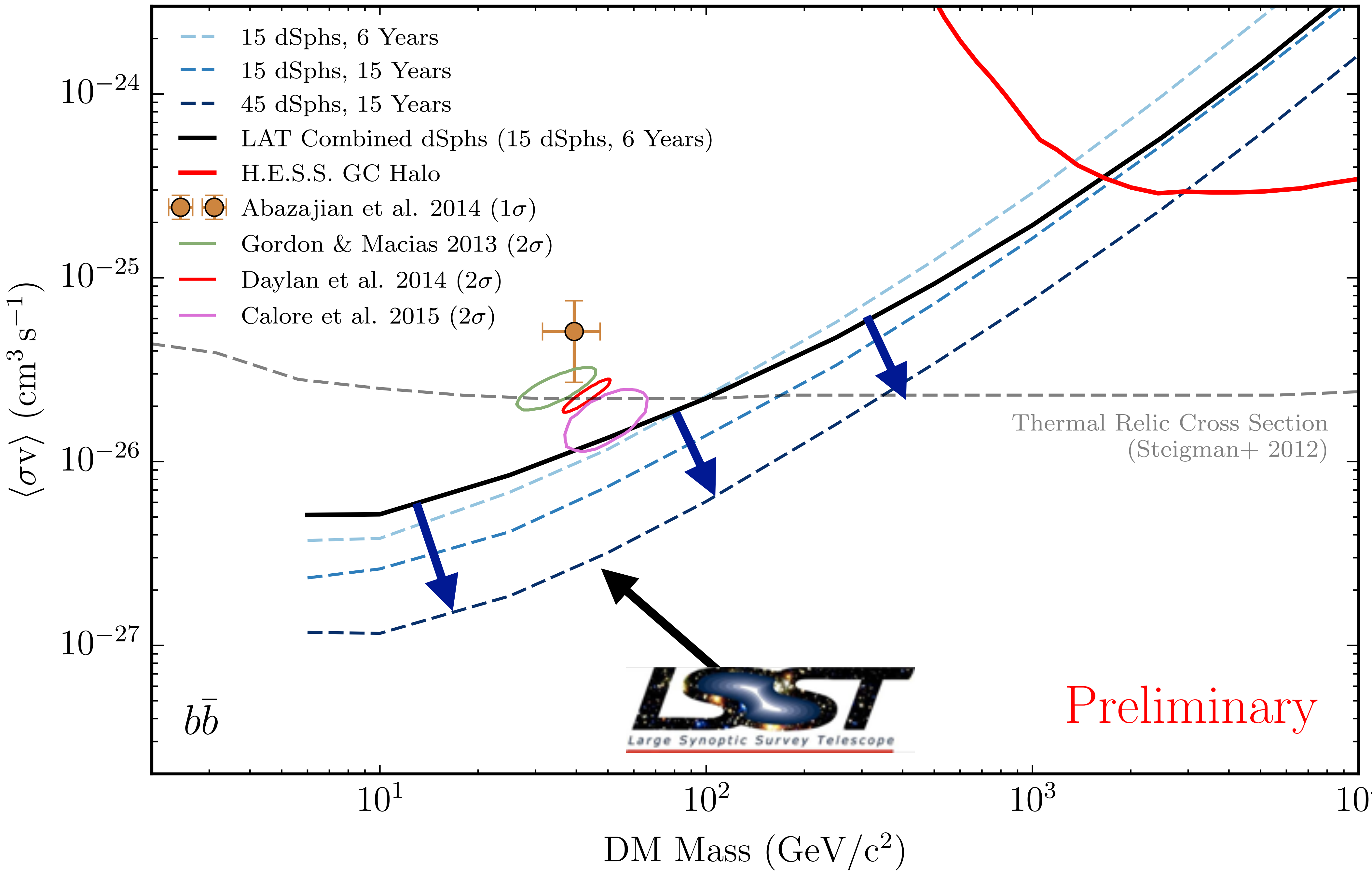


Cuoco et al. (2015) [1506.01030]

Shirasaki et al. (2015) [1511.07092]

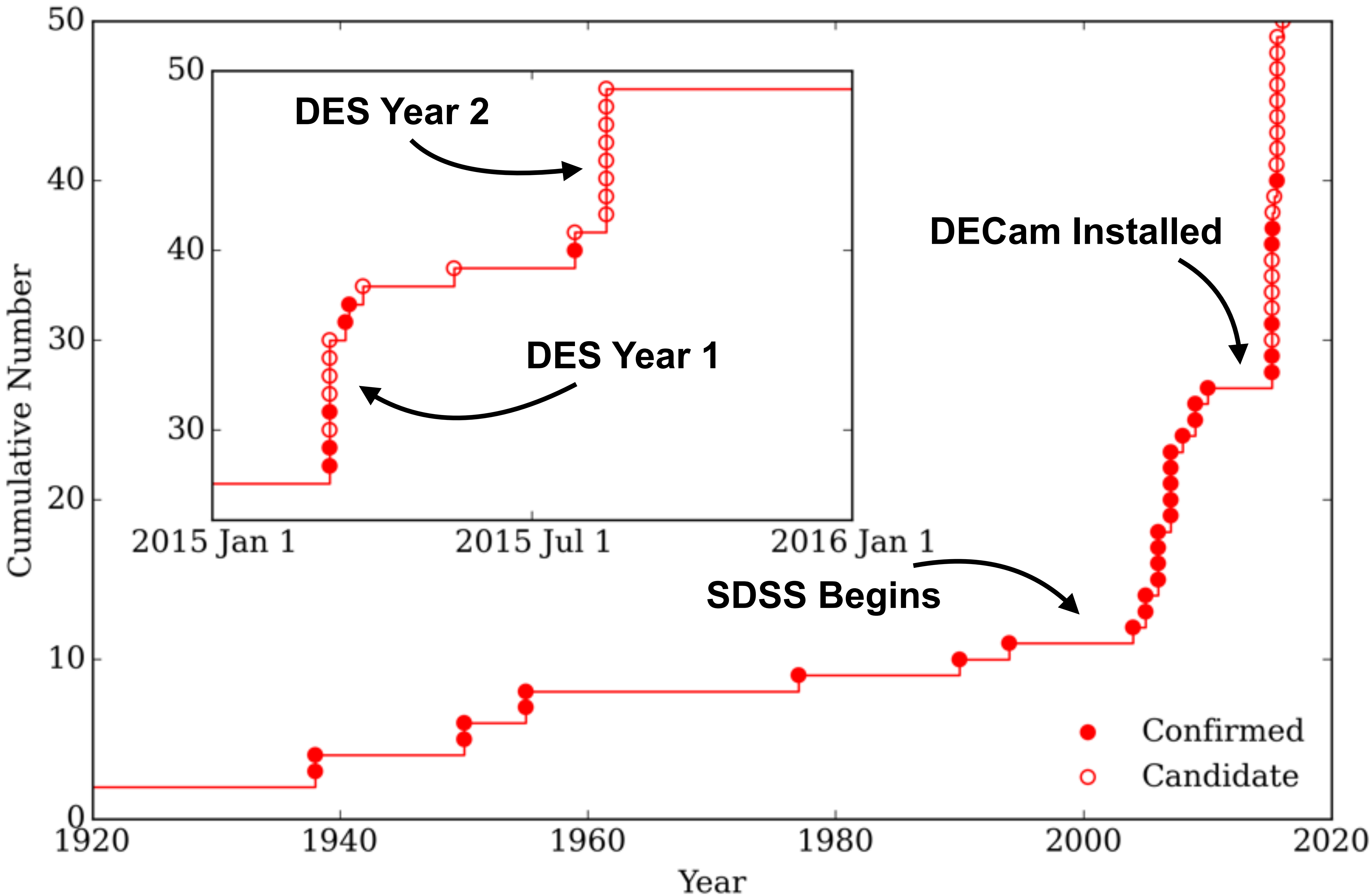
Shirasaki et al. (2014) [1404.5503]

Dwarf Galaxies

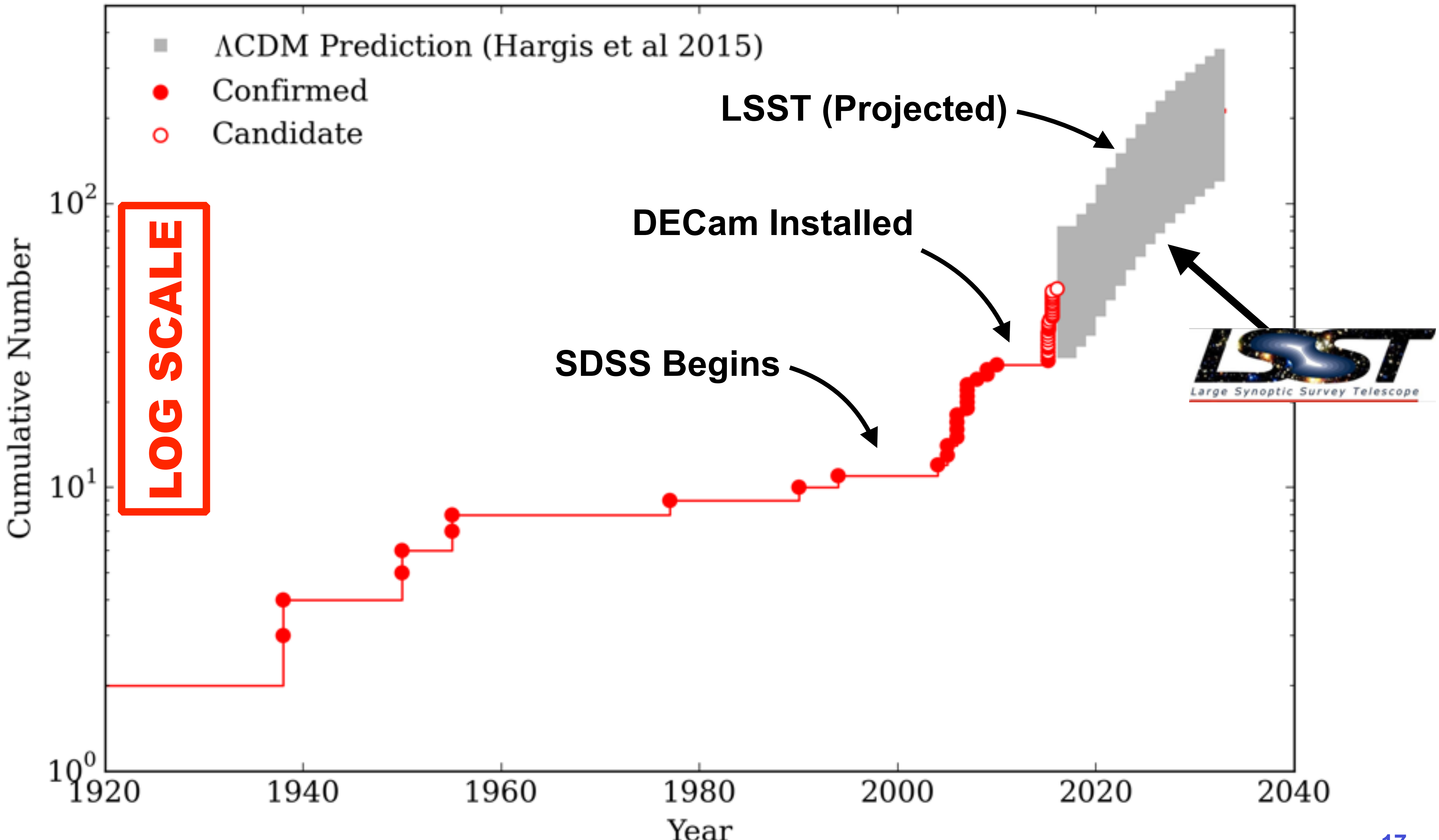


See Charles et al. 2016 [1605.02016]

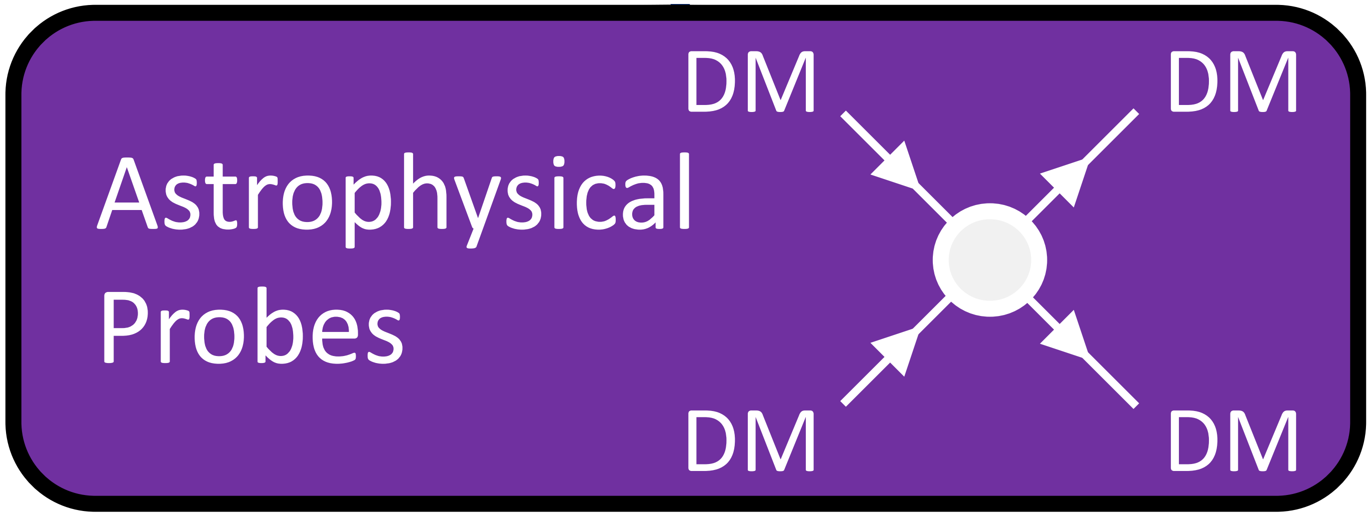
“Missing” Satellites?

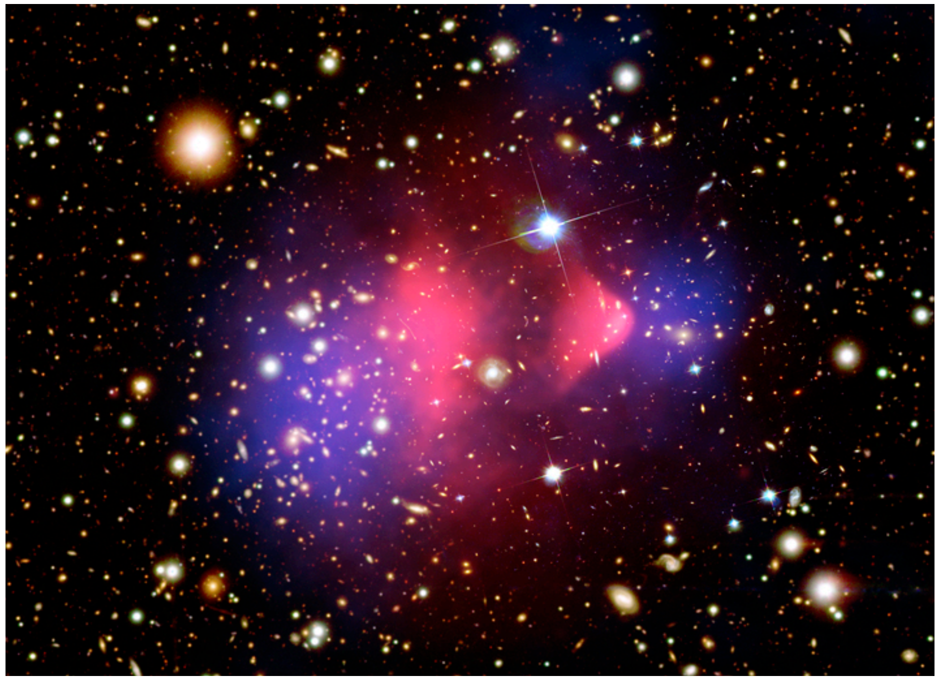


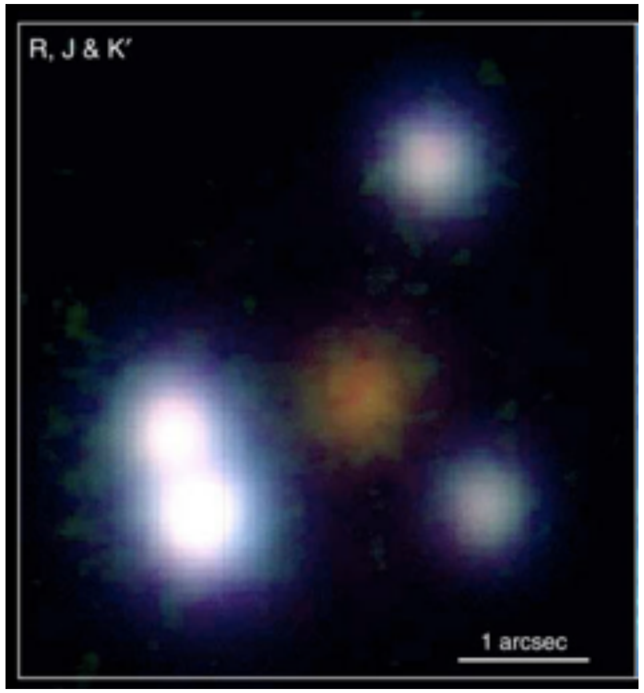
“Missing” Satellites?



Astrophysical Probes

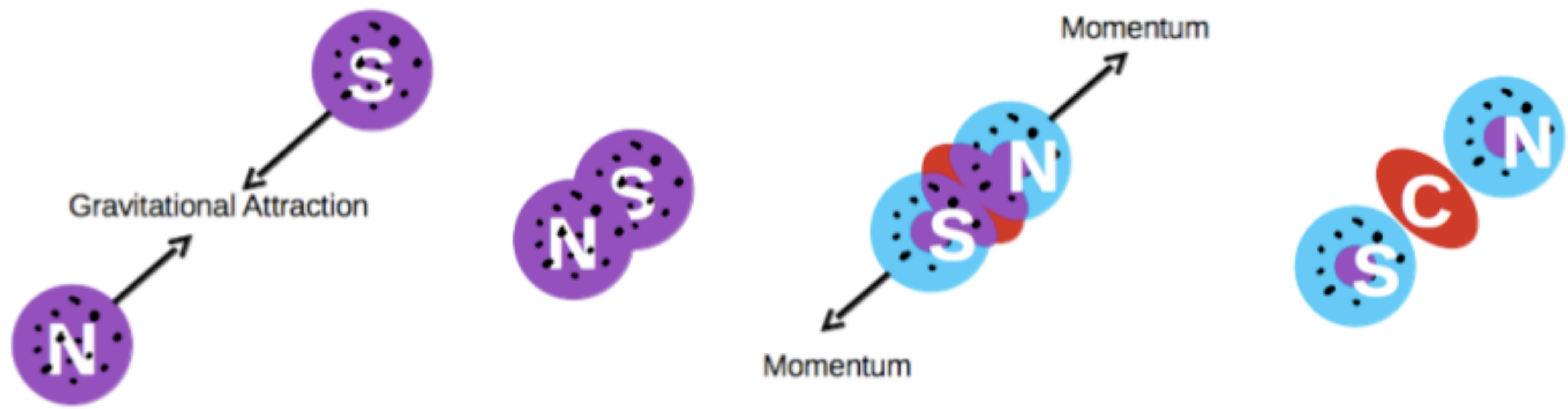




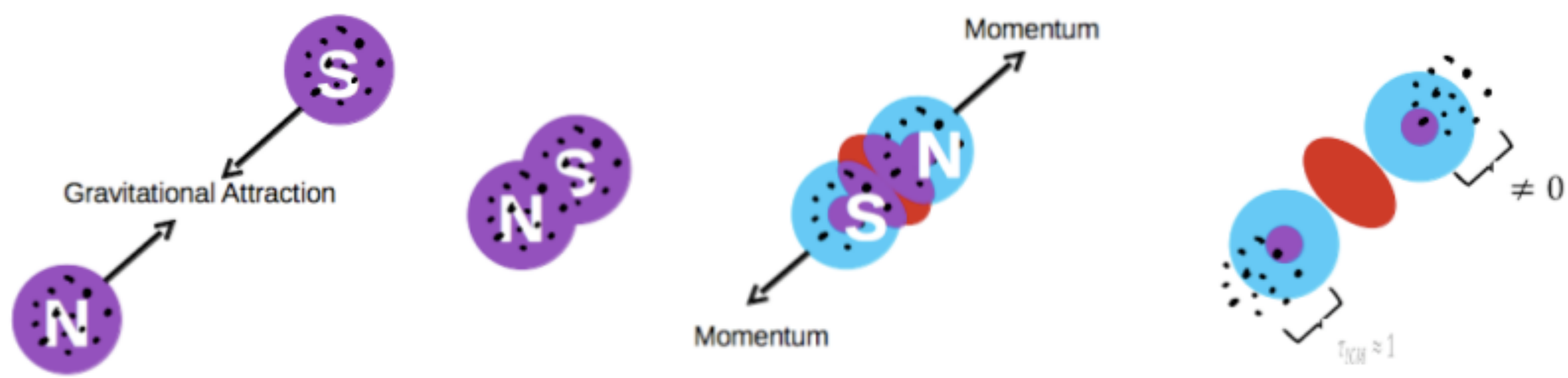


Self-Interacting Dark Matter

Non-Interacting Dark Matter



Self-Interacting Dark Matter

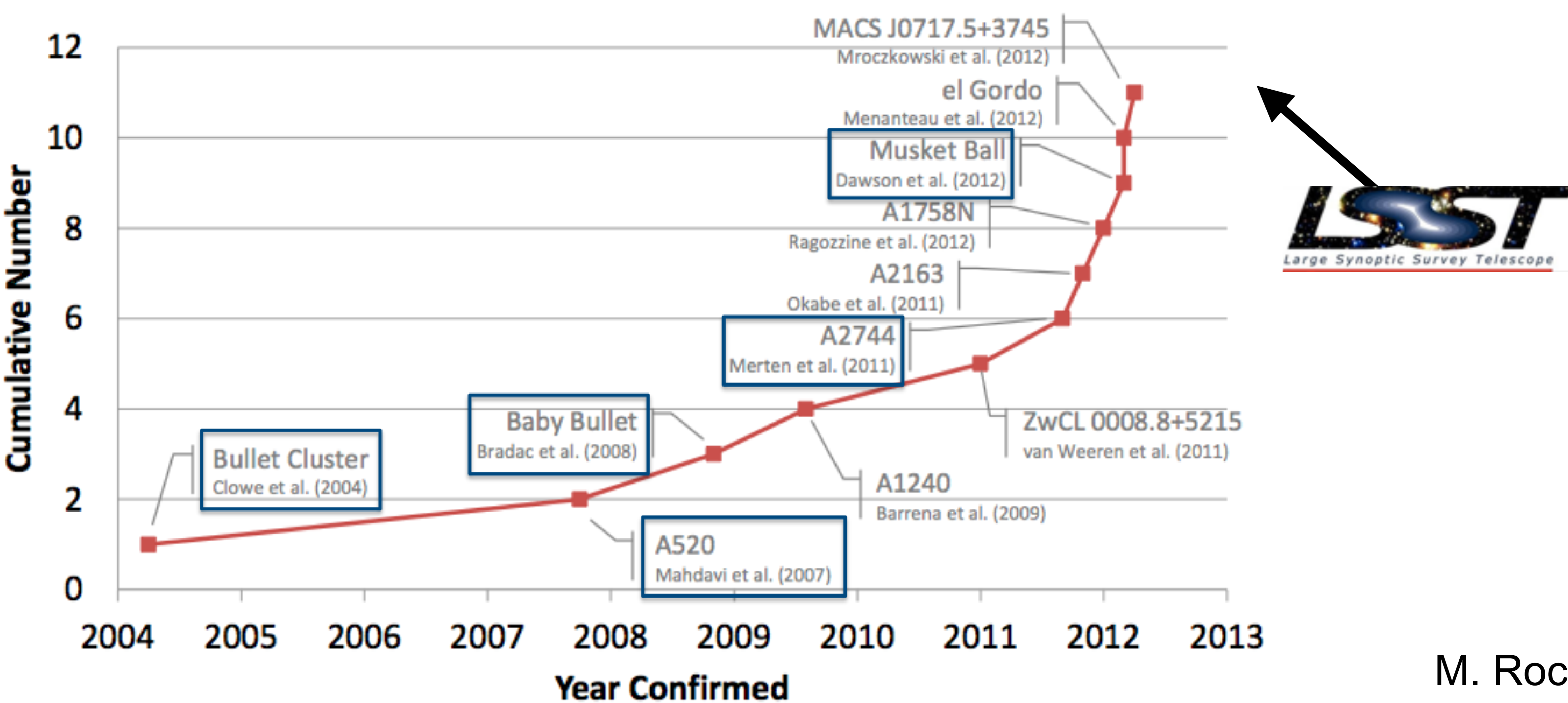


D. Wittman

Self-Interacting Dark Matter

W. Dawson

(Clowe et al. 2006) (Jee et al. 2012) (Bradac et al. 2008) (Dawson et al. 2012) (Rocha et al. 2012)



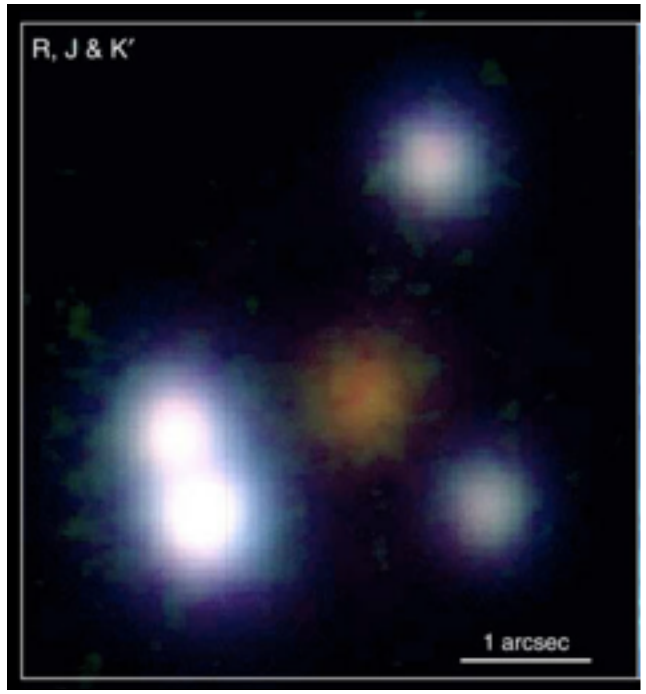
M. Rocha

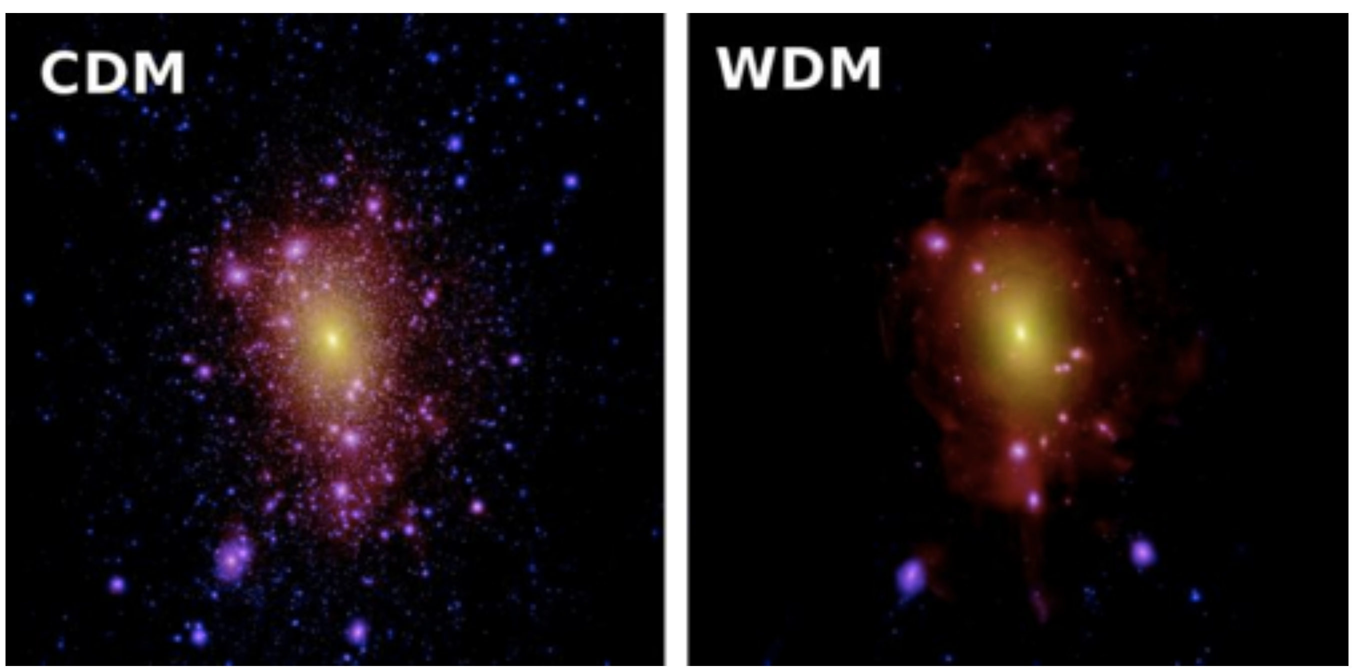
Strong Lensing and “Missing” Satellites

Mass modeling of galaxy-scale lenses

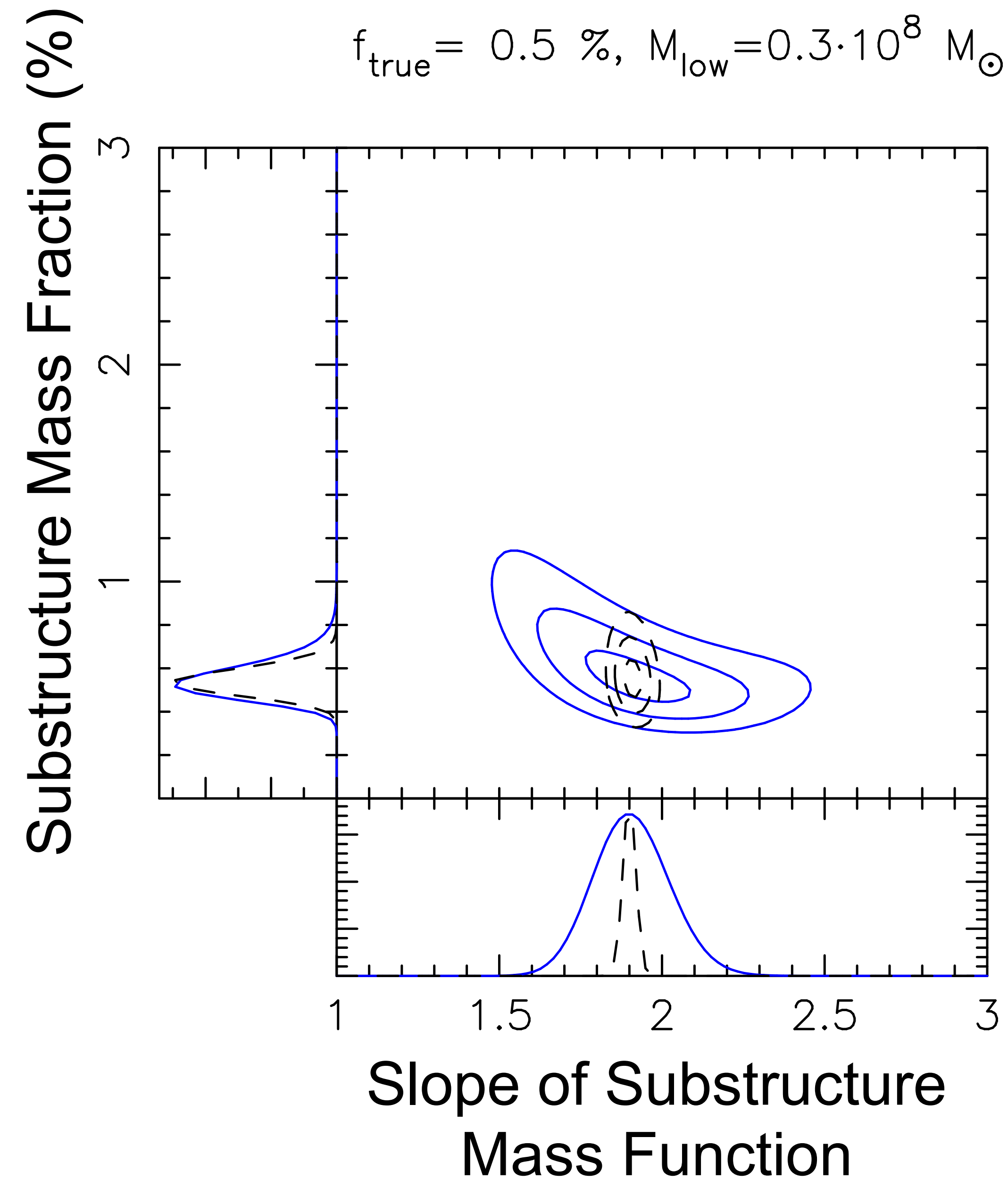
Flux ratios can be used to measure the contribution of substructure

Strong predictions from LCDM





Lovell et al. (2013) [1308.1399]

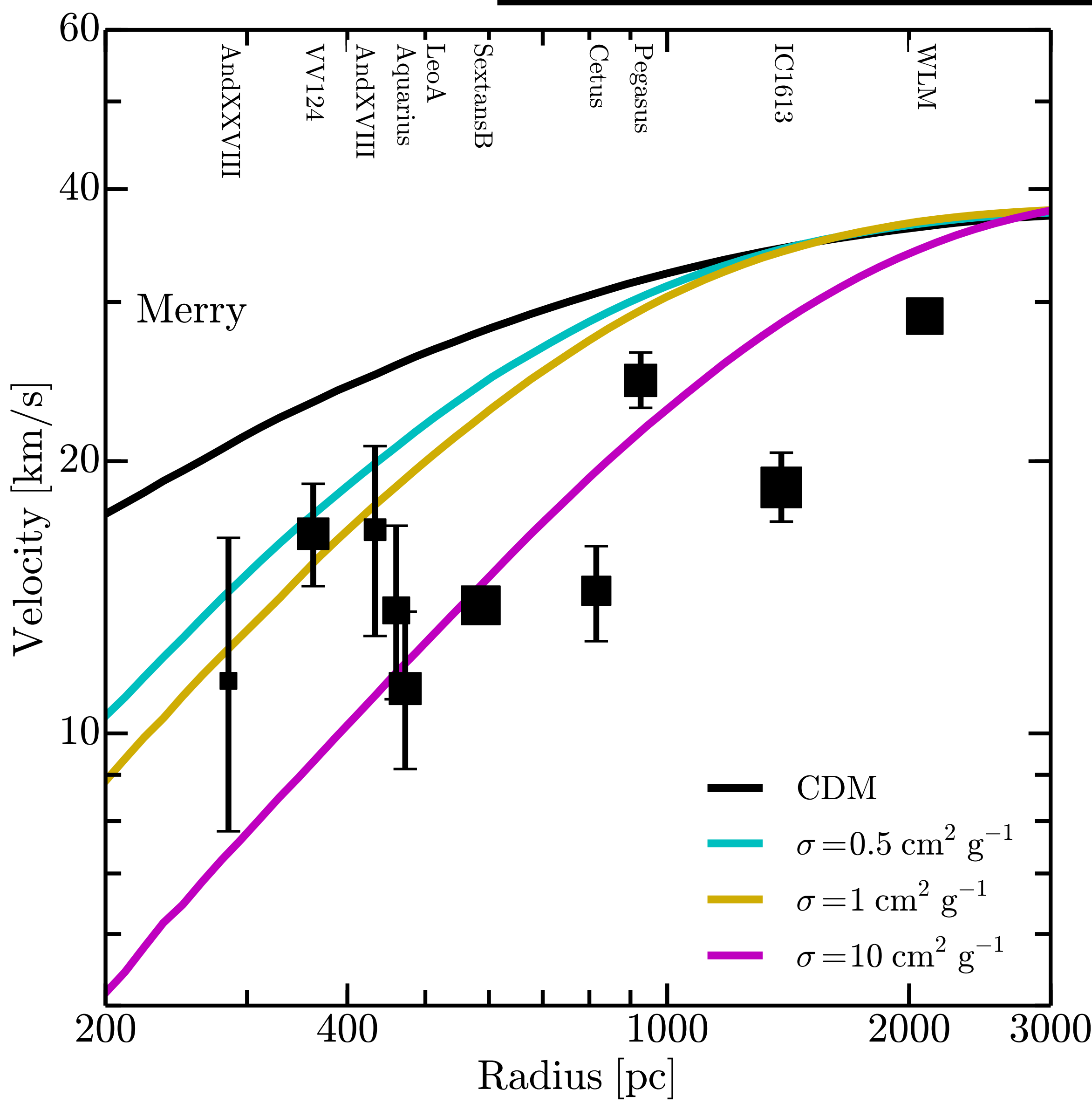


Dalal & Kochanek (2002) [55152]
Vegetti & Koopmans (2009) [0903.4752]
Hezavah et al. (2014) [1403.2720]

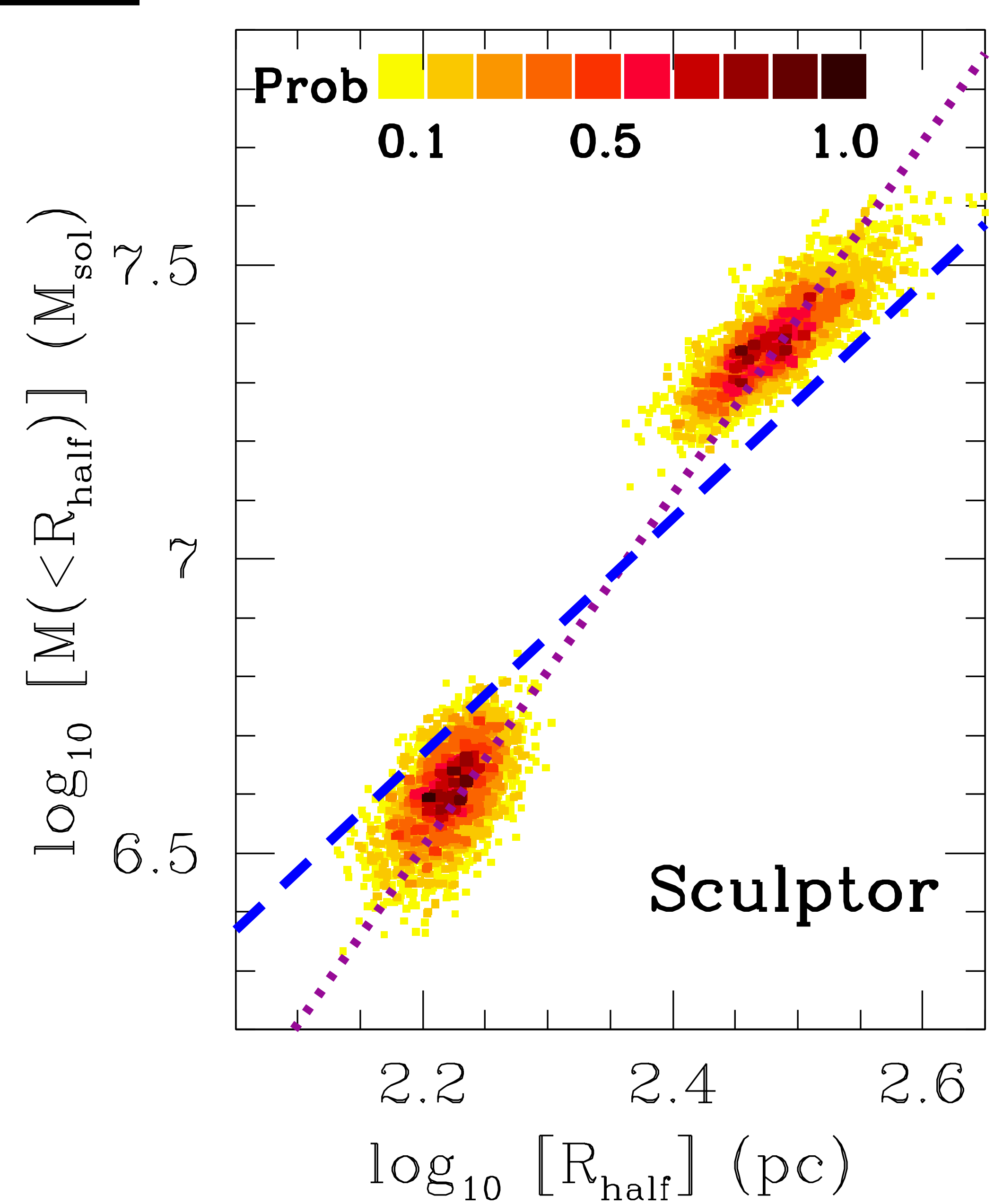
Too Big to Fail

WDM and SIDM can produce cores in dwarf galaxies

… so can baryonic feedback



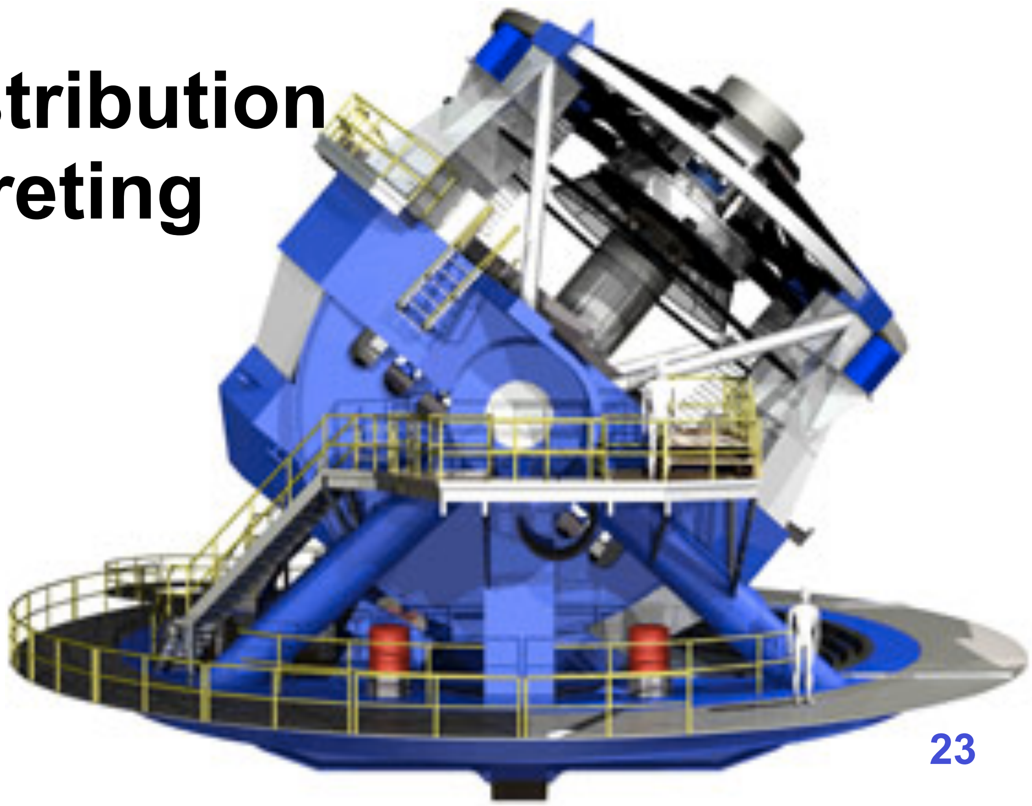
Elbert et al. (2014) [1412.1477]
Vogelsberger et al. (2014) [1405.5216]
Lovell et al. (2013) [1308.1399]



Walker & Peñarrubia (2011) [1108.2404]

Summary

- We would like to understand the fundamental unit of dark matter.
- Our knowledge is currently limited to “Astrophysical Probes”.
- LSST (with complementary instruments) will greatly increase the strength of these probes.
- Mapping the distribution of dark matter tells us where to look with other experiments (cross correlation?).
- Understanding the astrophysical distribution of dark matter is essential for interpreting any particle dark matter detection.



Extra Slides

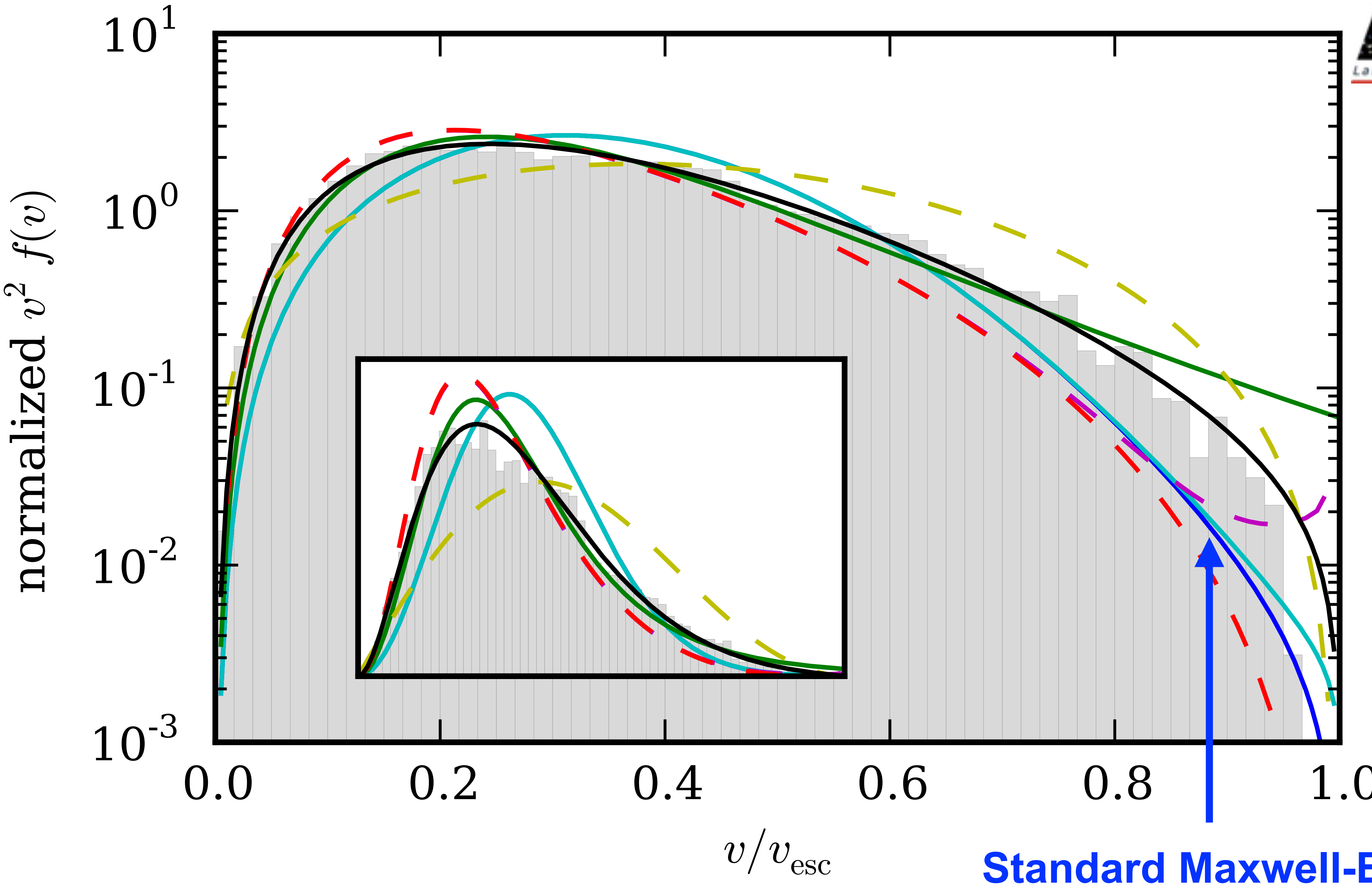
Rate calculation

- The differential cross section (for spin-independent interactions) per kilogram of target mass per unit recoil energy is

$$\frac{dR}{dQ} = \frac{\rho_0}{m_\chi} \times \frac{\sigma_0 A^2}{2\mu_p^2} \times F^2(Q) \times \int_{v_m} \frac{f(v)}{v} dv \quad (1)$$

- Dark matter density component, from local and galactic observations
- The unknown particle physics component, hopefully determined by experiment
  - Proportional to A^2 for most models (written explicitly here)
- The nuclear part, approximately given by $F^2(Q) \propto e^{-Q/Q_0}$ where $Q_0 \sim \frac{80}{A^{5/3}}$ MeV
- The velocity distribution of dark matter in the galaxy - $v_m = \sqrt{Qm_N/2m_r^2}$

Local Dark Matter Velocity



Mao et al. (2012) [1210.2721]